Seamless seasonal-to-decadal prediction with EC-Earth

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with contributions from IC3's CFU group and Bert Wouters (KNMI)

Outline

- Dynamical seasonal forecasting: systematic errors
- Seasonal forecasting, the first few months
- Seasonal forecasting beyond a few months
- Forecasting beyond the first year: comparison with other systems
- Global-average temperature and trends
- Summary

Ensemble climate forecast systems

Assume an ensemble forecast system with coupled initialized GCMs

Lead time = 3

May 87   Aug 87   Nov 87   Feb 88   May 88
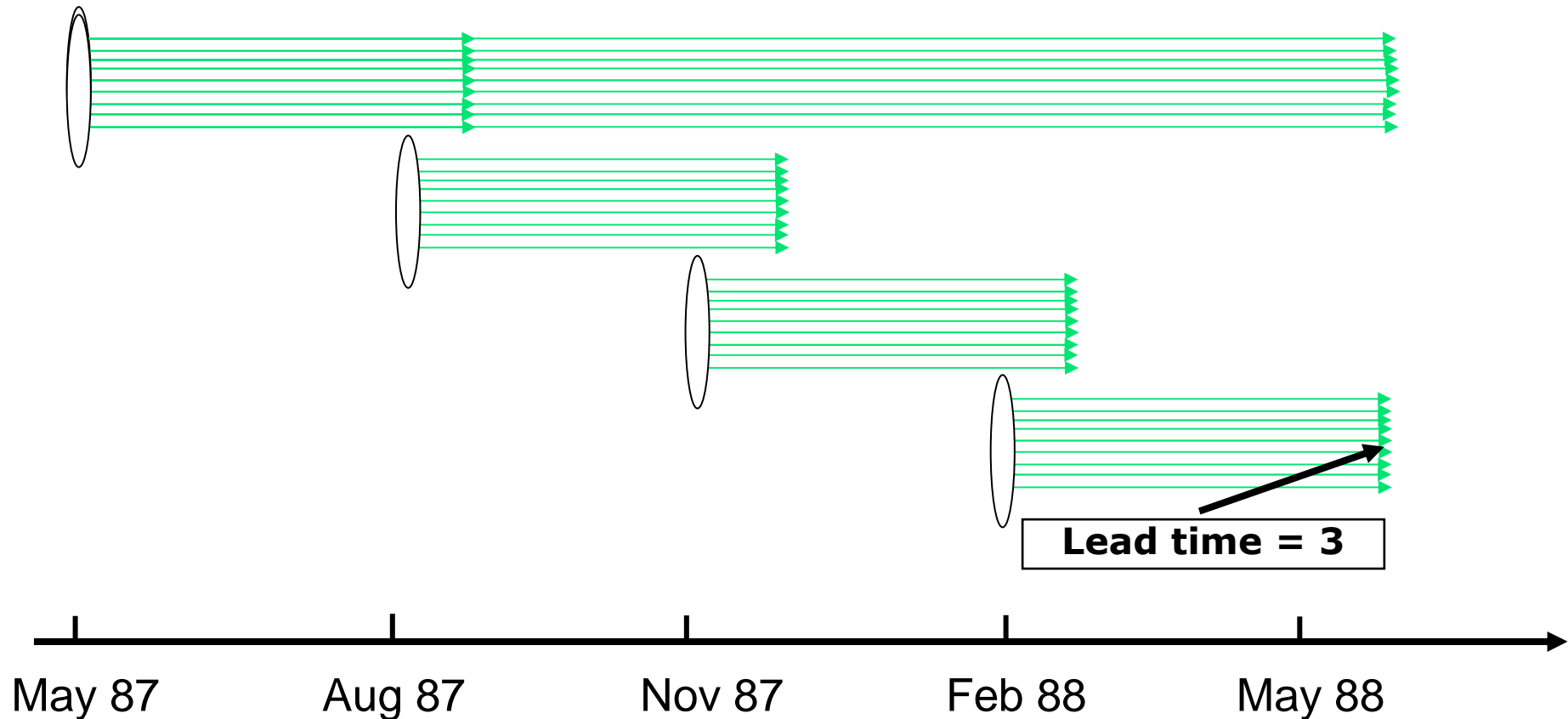
Simple empirical model: persistence

Correlation (solid line p value) of a Niño3.4 persistence model based on lagged linear regression of HadISST over 1981-2009; first regression model with data for 1951-1980.
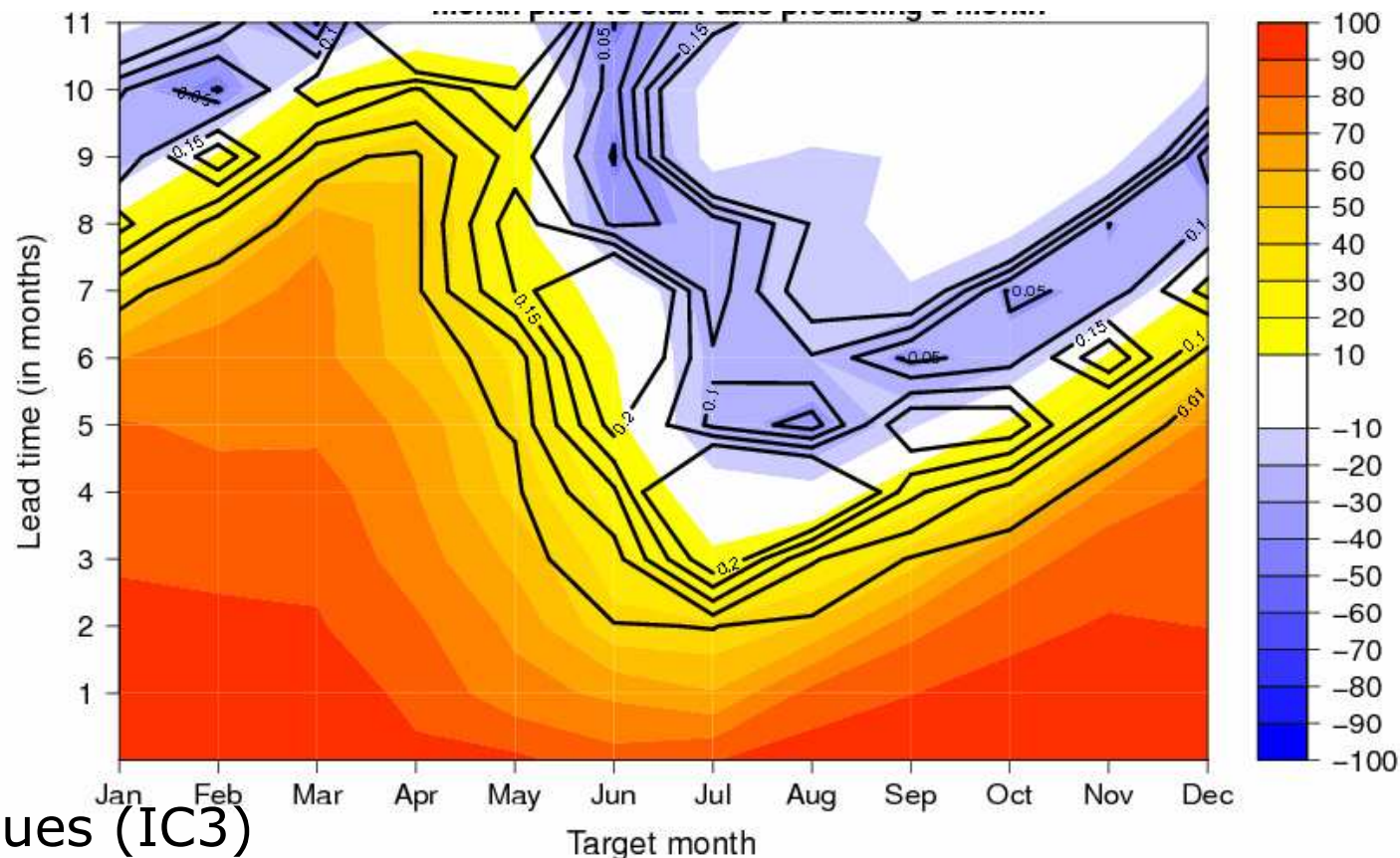
L. Rodrigues (IC3)

Seasonal forecast experimental setup

- Two forecast systems: System 3 (IFS/HOPE) and EC-Earth v2.2 (IFS/NEMO)

- Initial conditions: ERA40/ERAInt atmosphere and land, ORA-S3 and NEMOVAR-COMBINE ocean, DFS4.3 sea ice

- Five-member ensemble hindcasts up to 7 months

- Ensemble from five-member ocean analysis and atmospheric perturbations (singular vectors, plus SST perturbations in System 3) added to each member

- Initial conditions valid for 0 GMT on the 1st of a month

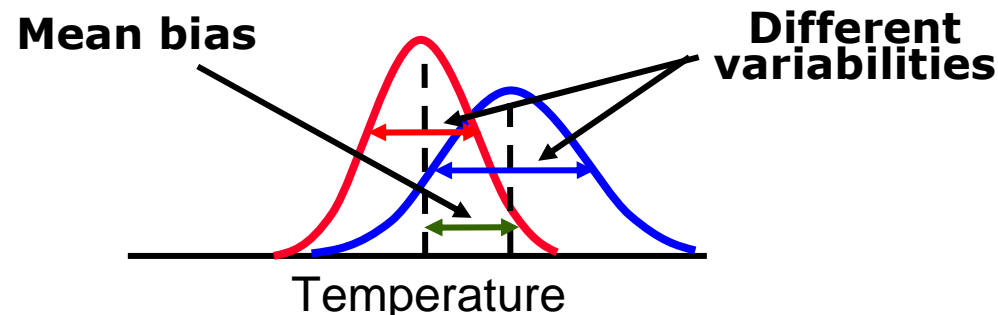- Four start dates per year: Feb, May, Aug and Nov.

- Forecast period 1981-2005

Systematic errors in ensemble forecasts

Main systematic errors in dynamical climate forecasts:

o **Differences between the model climatological pdf** (computed for a lead time from all start dates and ensemble members) **and the reference climatological pdf** (for the corresponding times of the reference dataset): systematic errors in mean and variability.

o **Conditional biases in the forecast pdf**: errors in conditional probabilities implying that probability forecasts are not trustworthy. This type of systematic error is best assessed using the **reliability diagram**.

Differences in climatological pdfs
Reference pdf   **Model pdf**

Mean bias   **Different variabilities**

Temperature

Forecast PDF
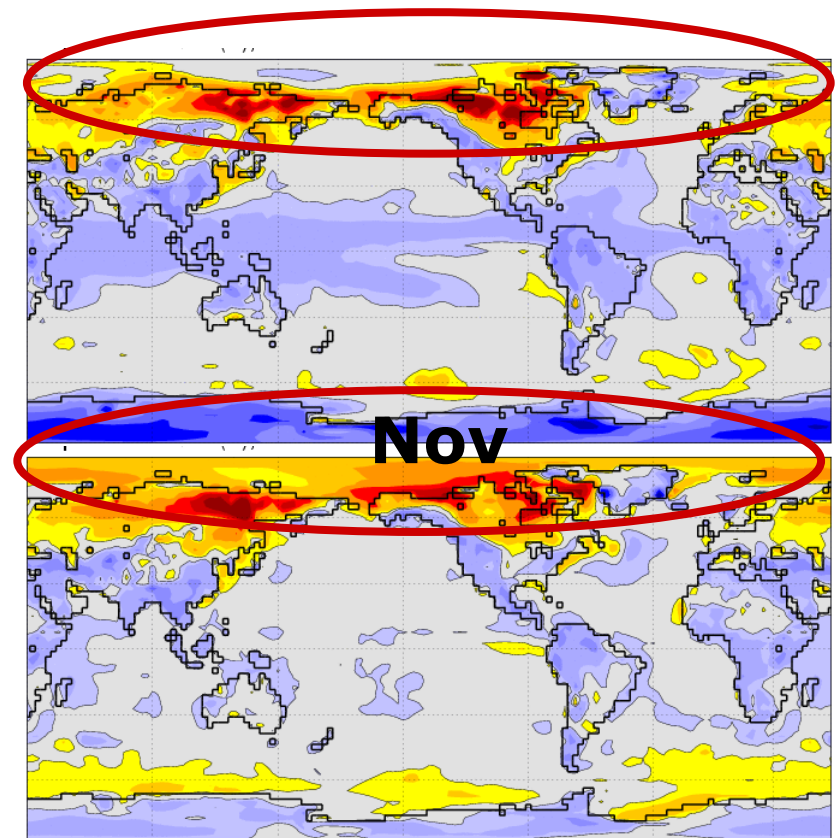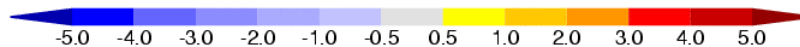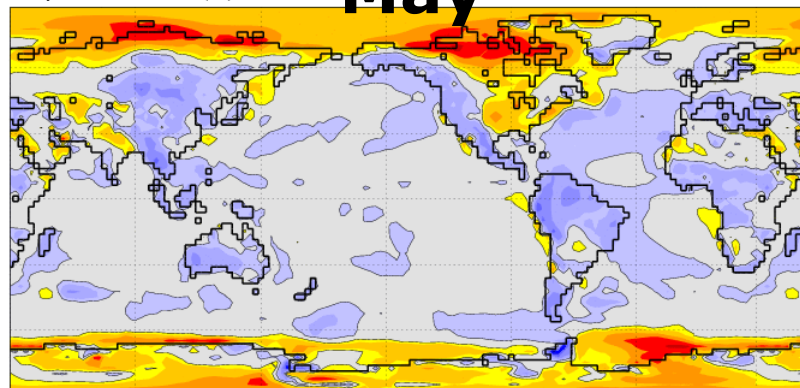
Actual occurrences

t=2
t=1
t=3

Threshold
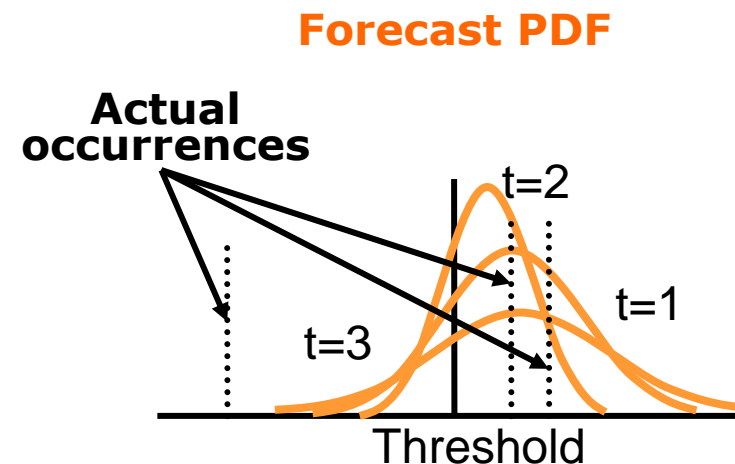
Seasonal predictions: mean bias

Bias of first month near-surface air temperature re-forecasts wrt ERA40/Int over 1976-2005.
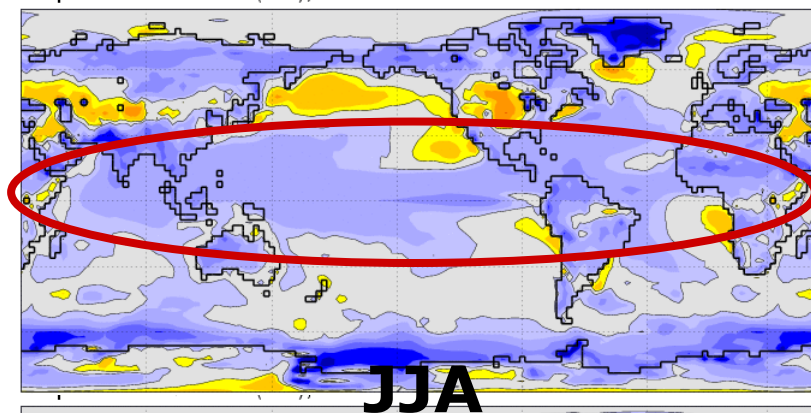
EC-Earth

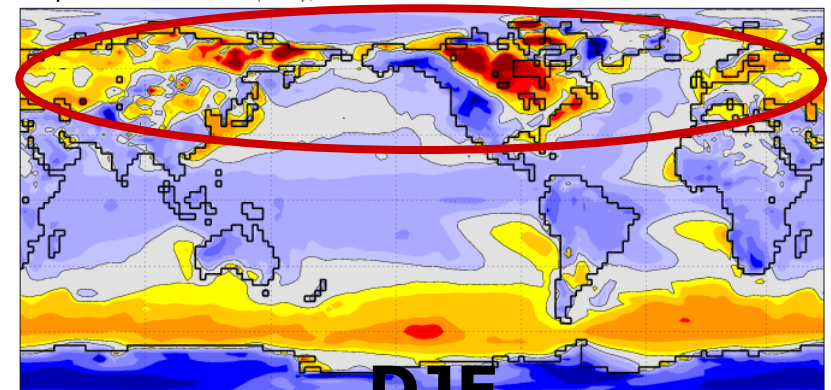**System 3**

May
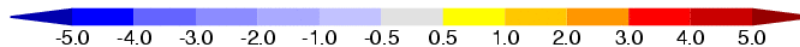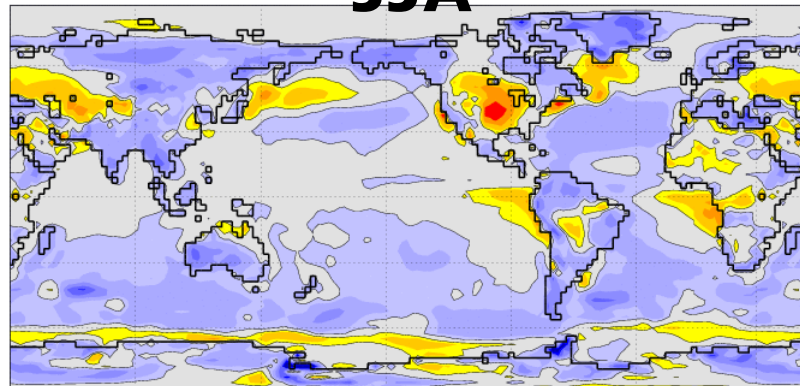
Nov
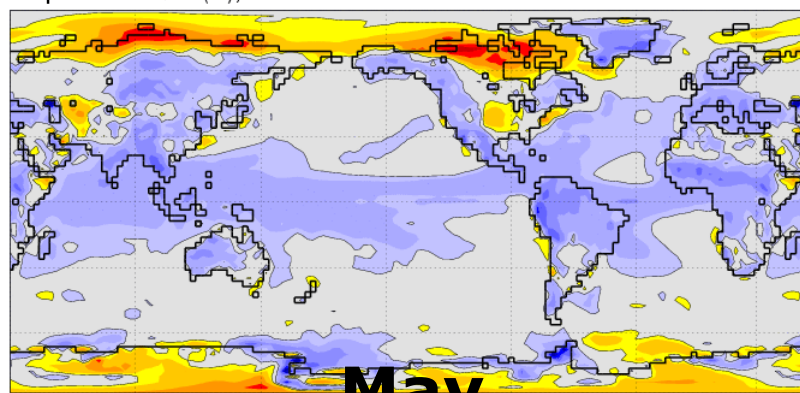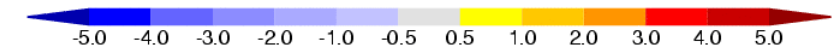
Seasonal predictions: mean bias

Bias of 2-4 month near-surface air temperature re-forecasts wrt ERA40/Int over 1976-2005.
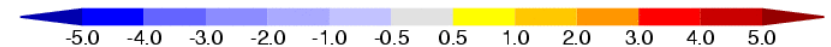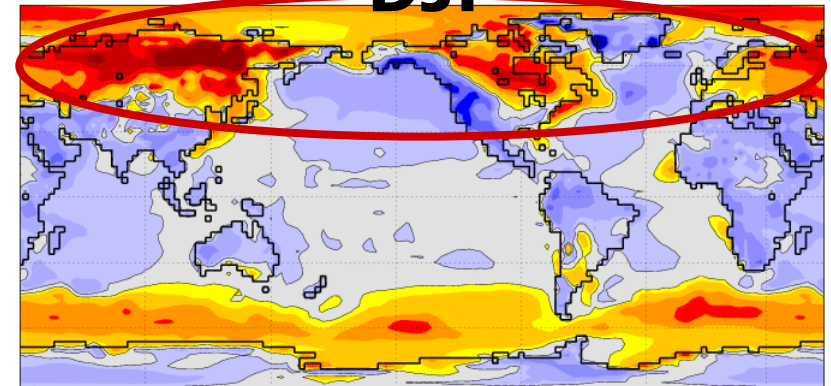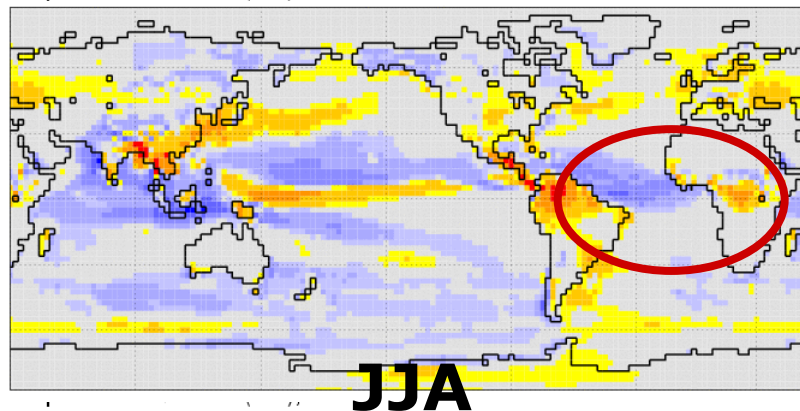

EC-Earth

System 3

JJA

DJF

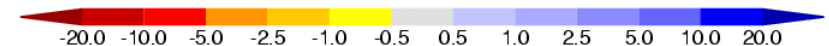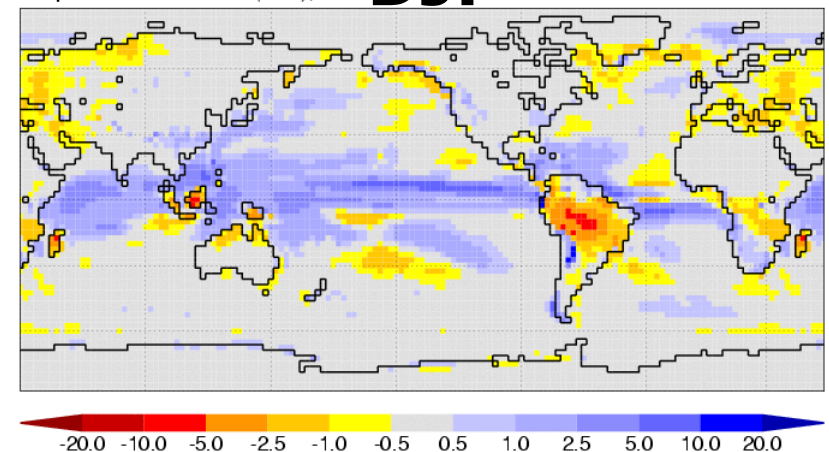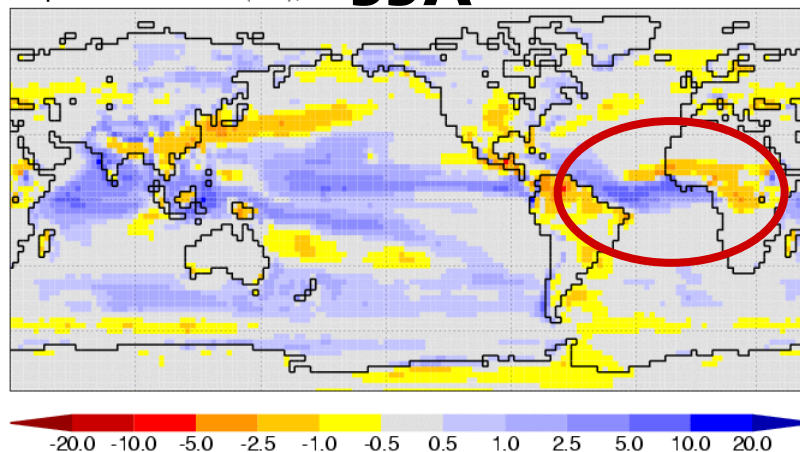# Seasonal predictions: mean bias

Bias of 2-4 month precipitation re-forecasts wrt GPCP over 1980-2005.
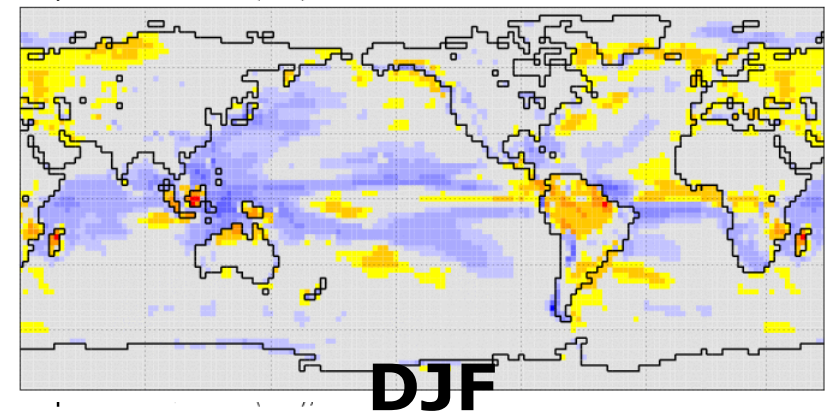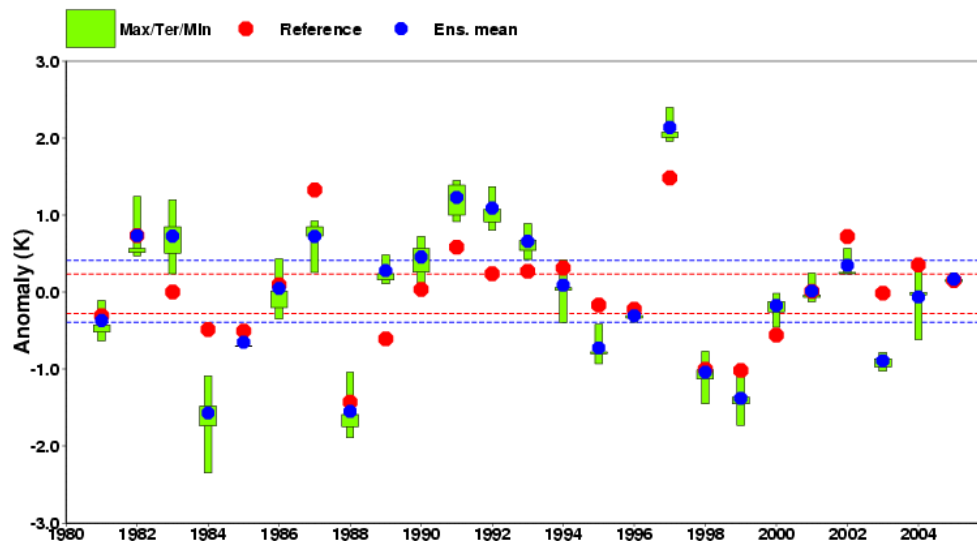
Seasonal predictions: ENSO

Niño3.4 time series for ERA40/Int (red dots), ensemble range (green box-and-whisker) and ensemble mean (blue dots) 2-4 month (JJA) re-forecasts over 1981-2005.

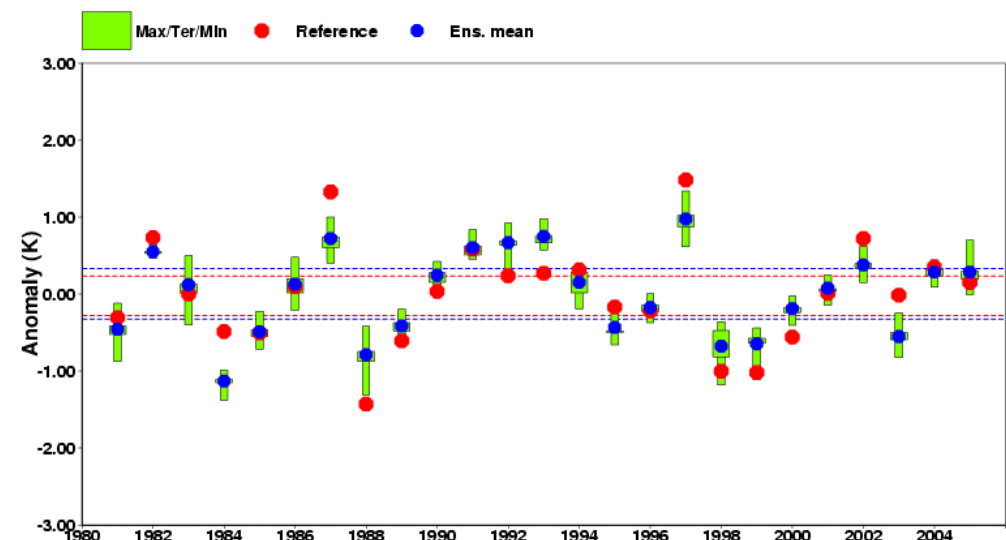**EC-Earth**
Ratio sd: 1.34
Corr: 0.82
RPSSd: 0.48

System 3
Ratio sd: 0.84
Corr: 0.86
RPSSd: 0.68

Seasonal predictions: regional skill

Anomaly correlation coefficient (and bootstrapped 95% confidence intervals) for first month and 2-4 month seasonal predictions of EC-Earth and System 3 ensemble near-surface temperature wrt ERA40/Int over 1981-2005.
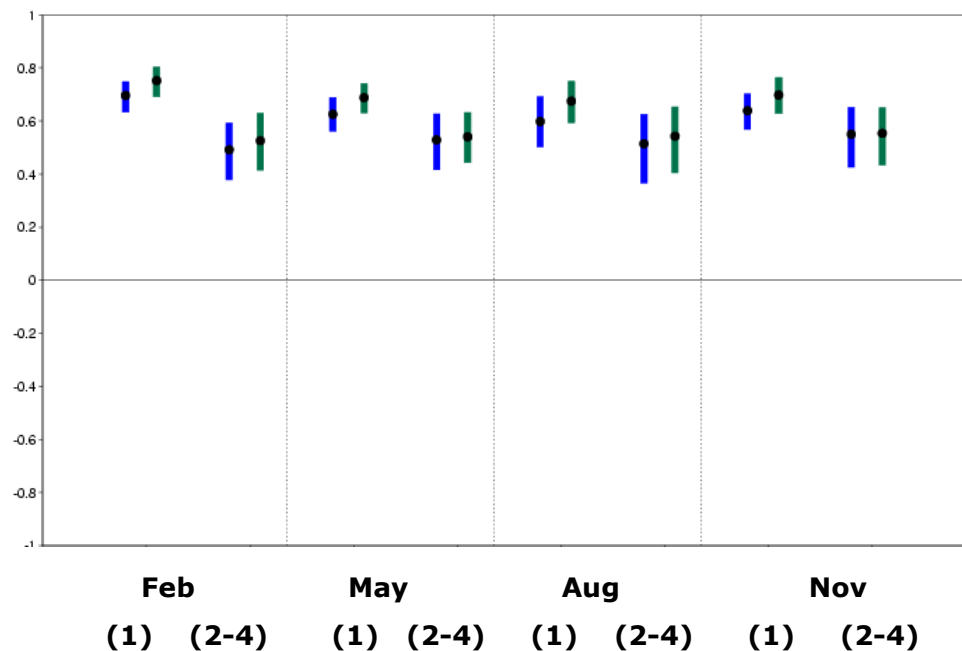

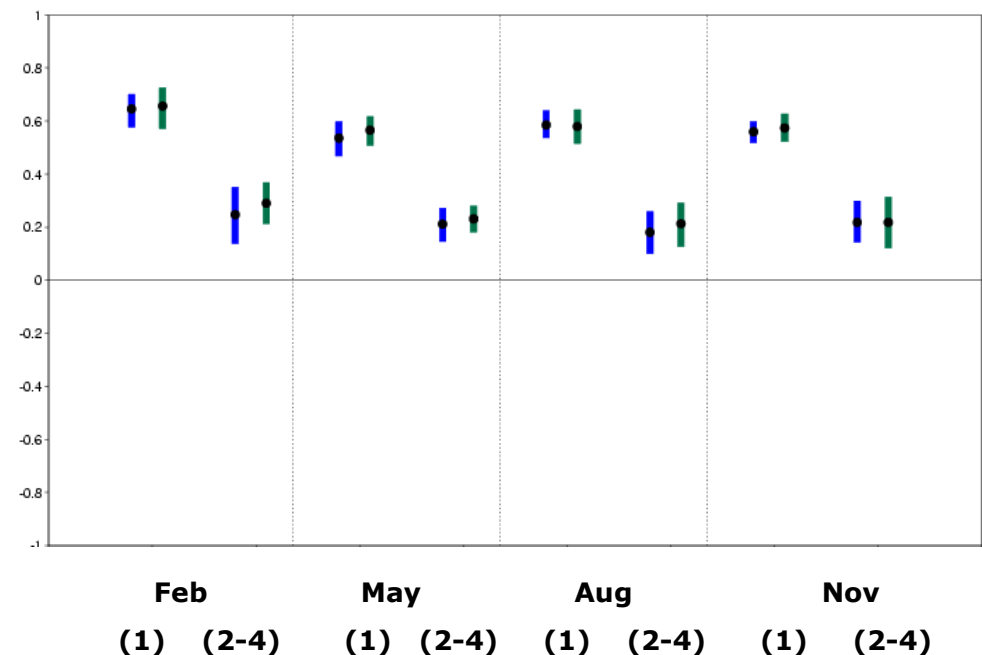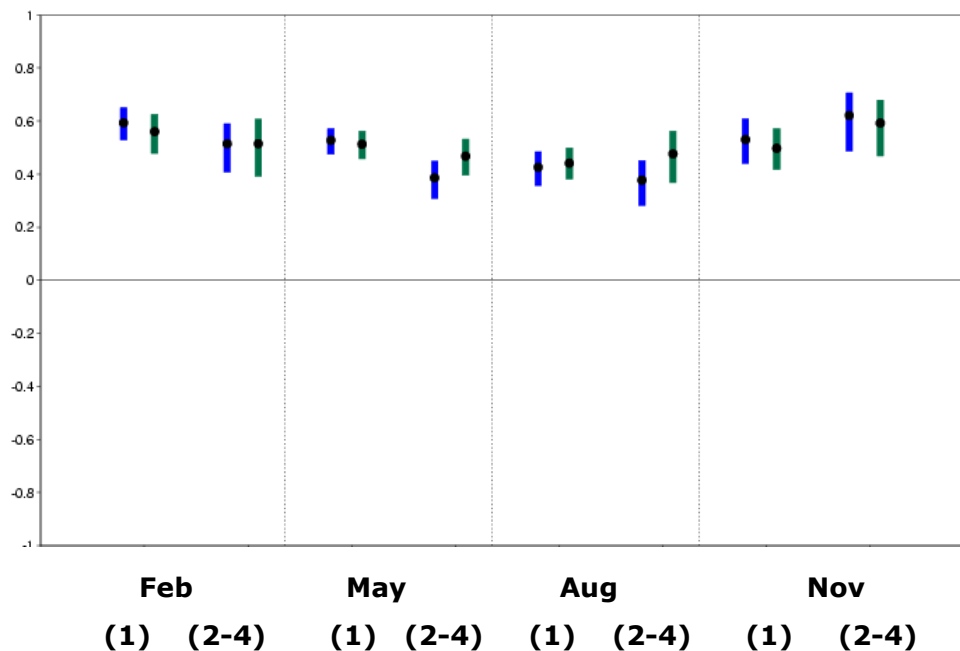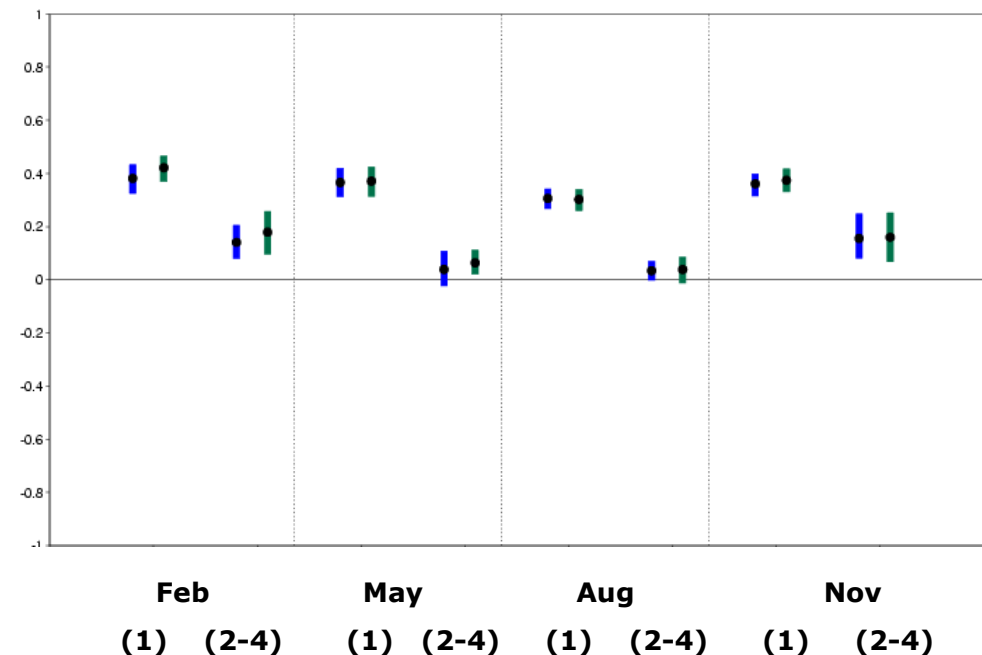**Tropics**

Northern Extratropics

Seasonal predictions: regional skill

Anomaly correlation coefficient (and bootstrapped 95% confidence intervals) for first month and 2-4 month seasonal predictions of EC-Earth and System 3 ensemble precipitation wrt GPCP over 1981-2005.
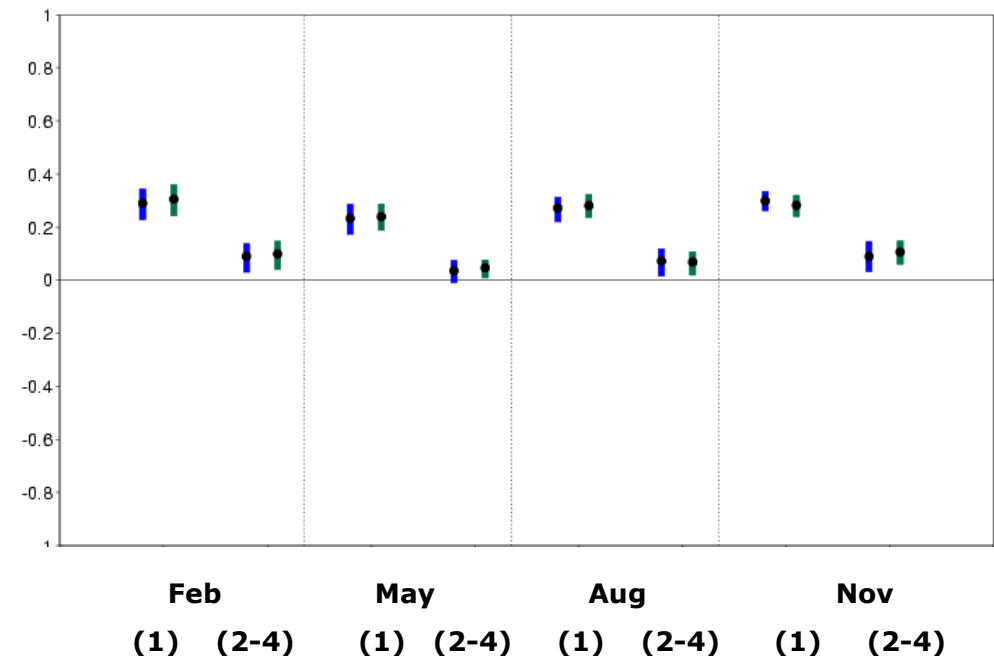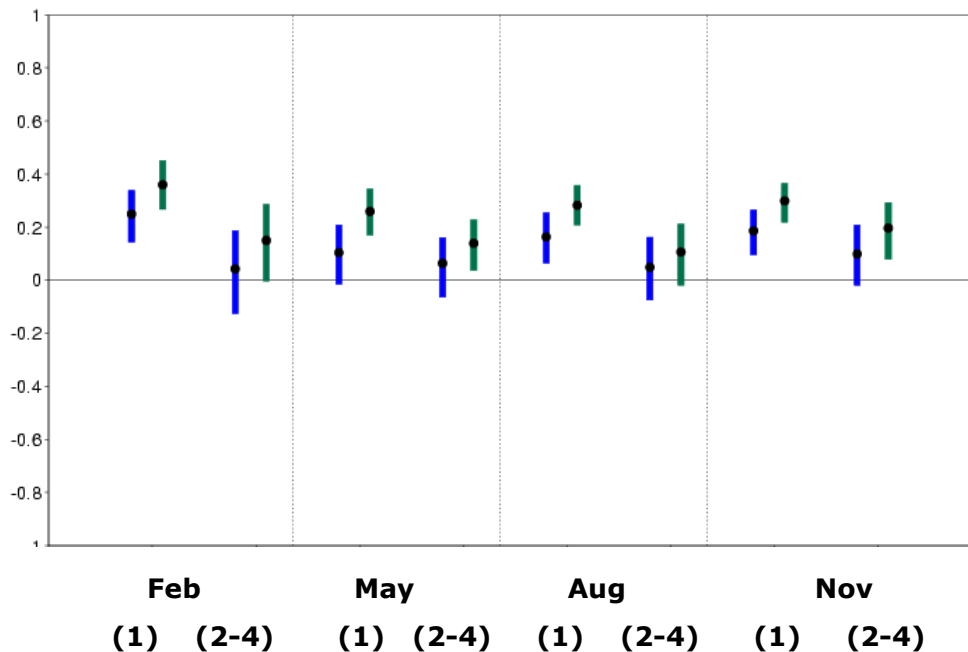
Seasonal predictions: regional skill

Infinite ensemble size Brier skill score (and bootstrapped 95% confidence intervals) for first month and 2-4 month seasonal predictions above the upper tercile of EC-Earth and System 3 ensemble near-surface temperature wrt ERA40/Int over 1981-2005.

Tropics

Northern Extratropics

Seasonal prediction: system comparison

ACC (left) and infinite ensemble size Brier skill score (right) for lead time 2-4, several regions (NH, Tropics, SH), events (anomalies above/below the upper/lower tercile), start dates (Feb, May, Aug and Nov) and variables (near-surface temperature, precipitation and MSLP) computed over the period 1981-2005. The numbers are for the cases a system is statistically significantly superior.
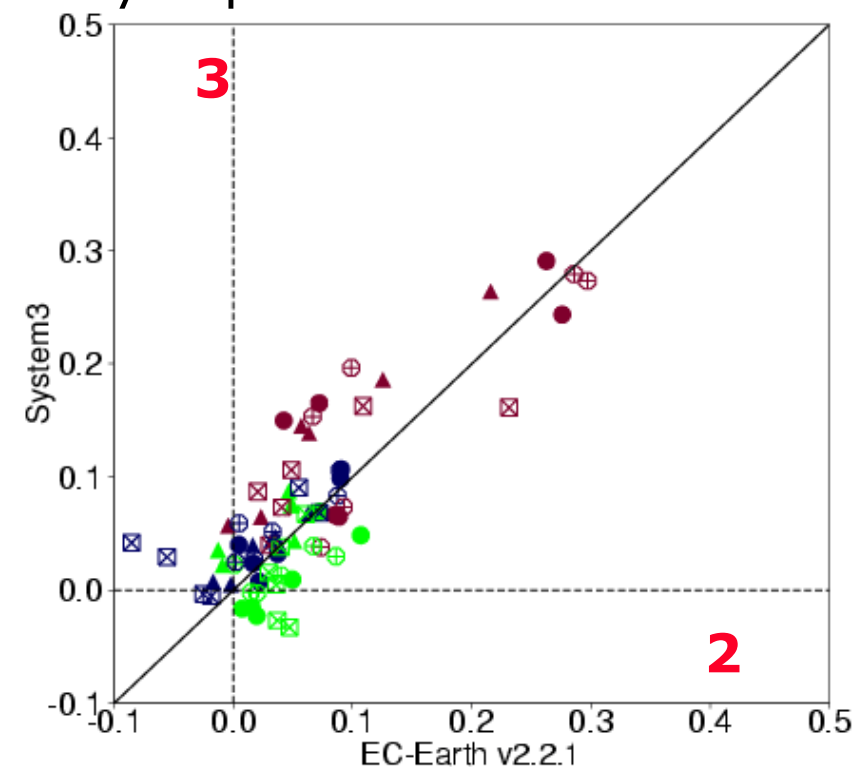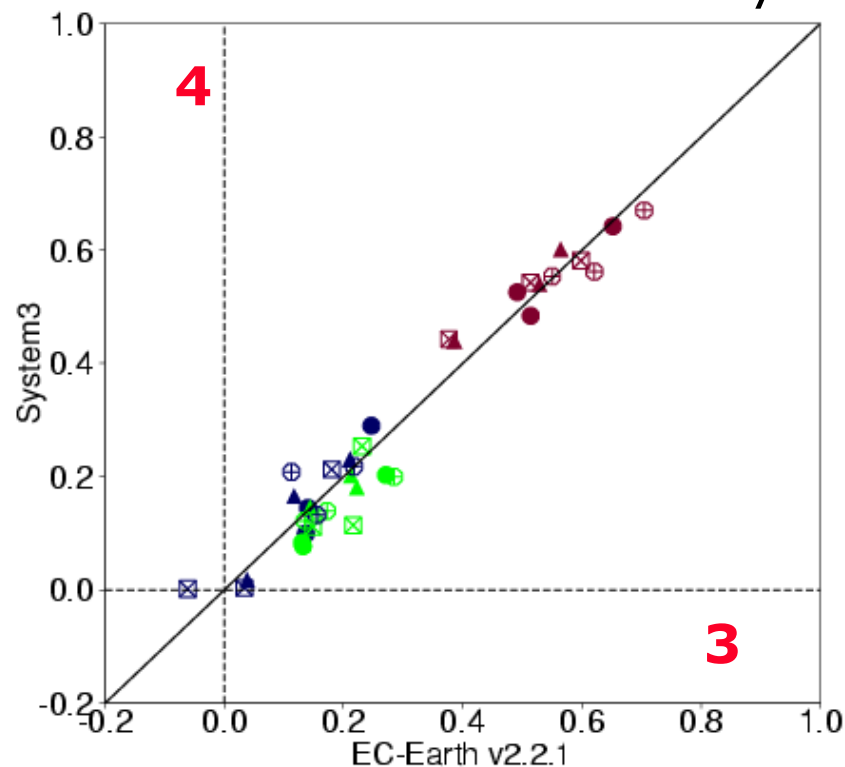
Seasonal predictions: sea-ice impact

Ensemble-mean correlation of EC-Earth near-surface air temperature 5-7 month (SON) re-forecasts wrt ERA40/Int over 1991-2005. Dots for values statistically significant with
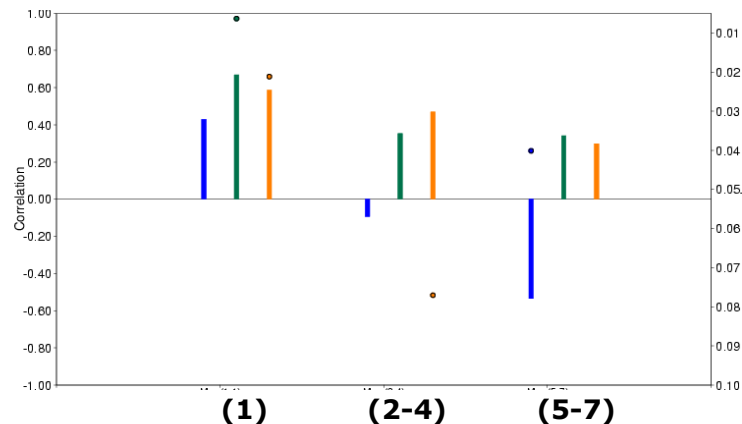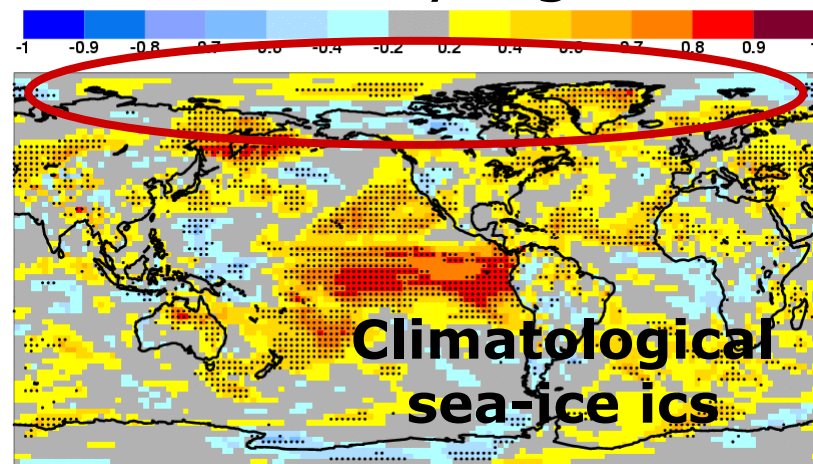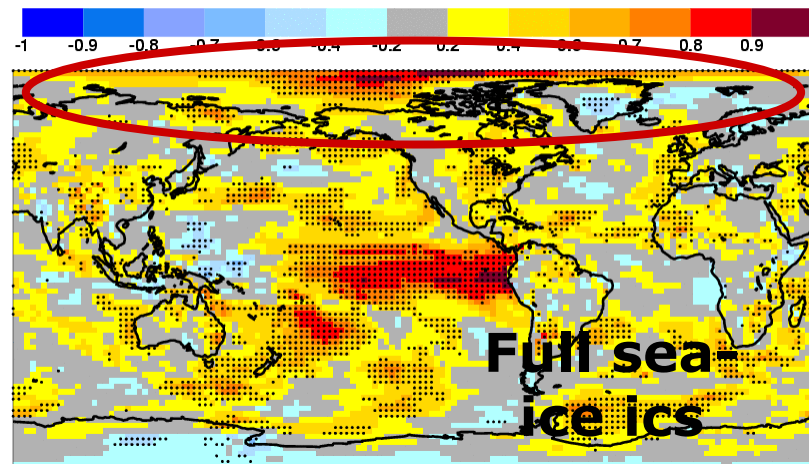
Correlation for NAO EC-Earth, System 3 and EC-Earth/clim. sea-ice ics May start date re-forecasts

Annual forecast experimental setup

- Two forecast systems: System 3 (IFS/HOPE) and EC-Earth v2.2 (IFS/NEMO), the latter also in AMIP mode

- Initial conditions: ERA40/ERAInt atmosphere and land, ORA-S3 and NEMOVAR-COMBINE ocean, DFS4.3 sea ice

- Five-member ensemble hindcasts up to 13 months

- Ensemble from five-member ocean analysis and atmospheric perturbations (singular vectors plus SST perturbations in System 3) added to each member

- Initial conditions valid for 0 GMT on the 1st of a month

- Two start dates per year: May and November
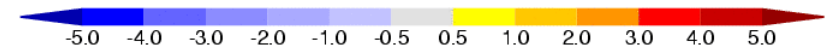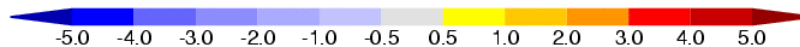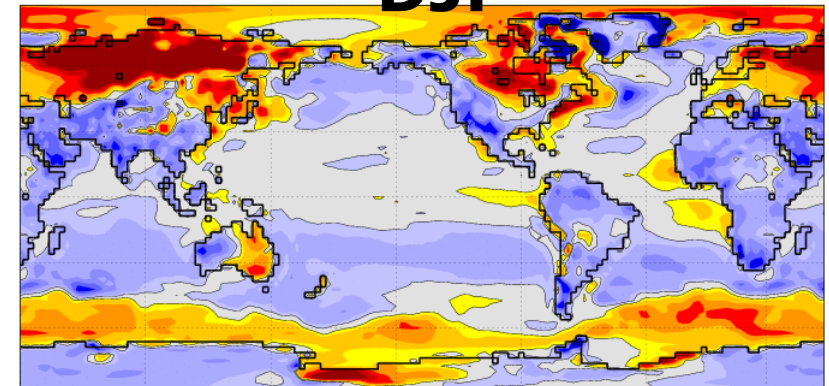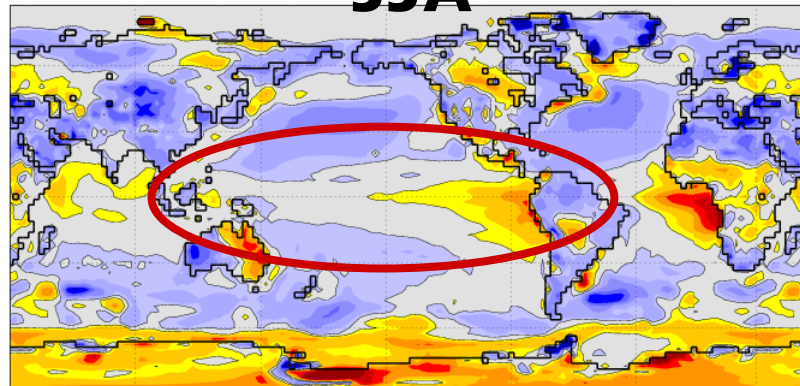
- Forecast period 1976-2005

Annual predictions: mean bias

Bias of 8-10 month near-surface air temperature re-forecasts wrt ERA40/Int over 1976-2005.
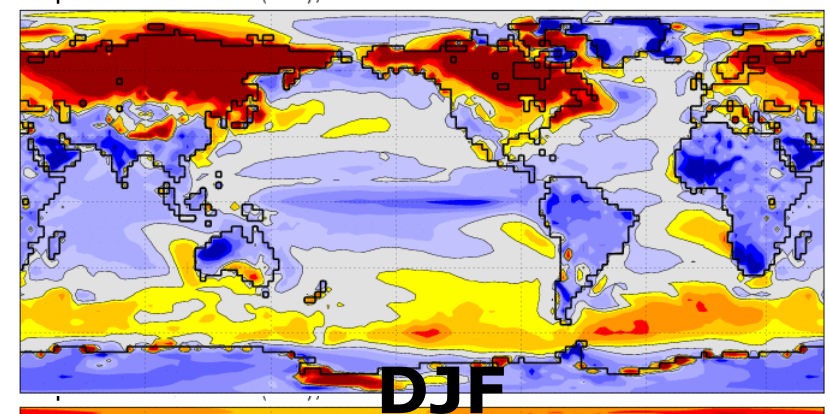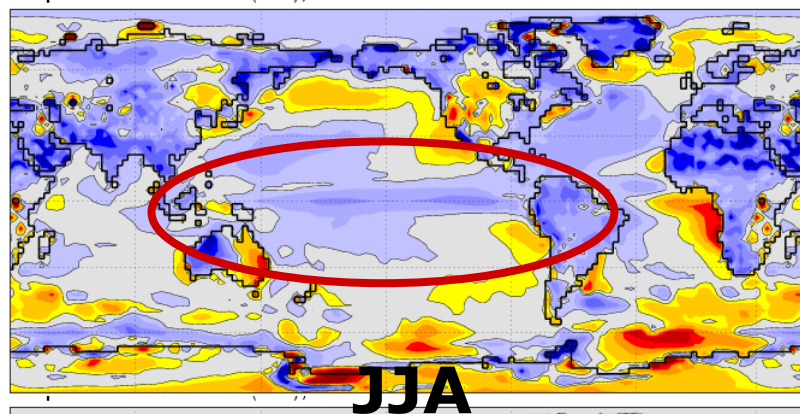
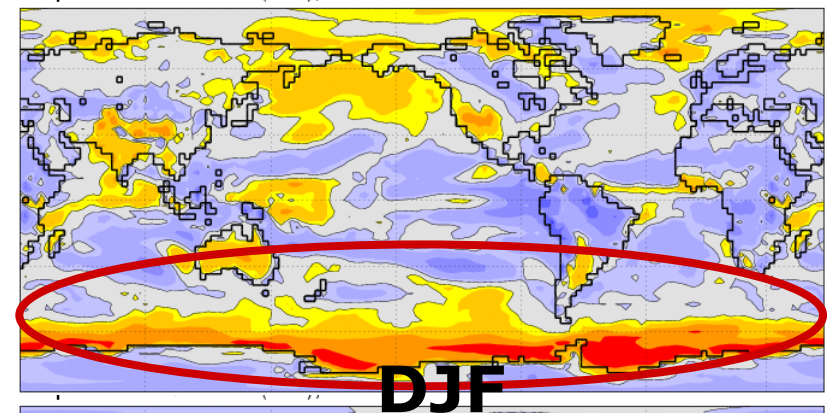# Annual predictions: standard deviation bias

Ratio of interannual standard deviation of 8-10 month near-surface air temperature re-forecasts wrt ERA40/Int over 1976-2005.
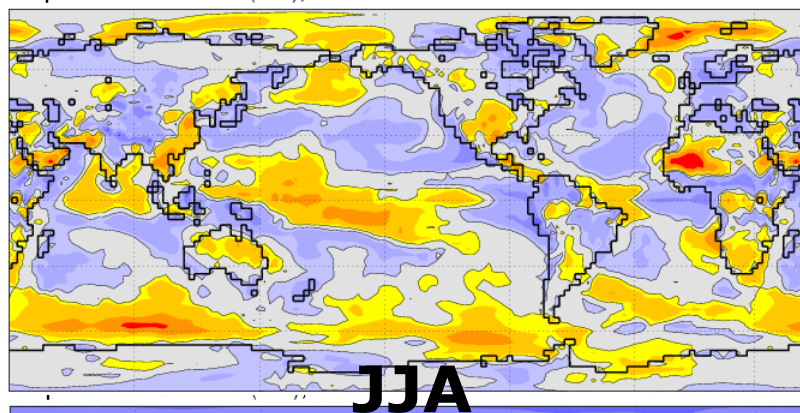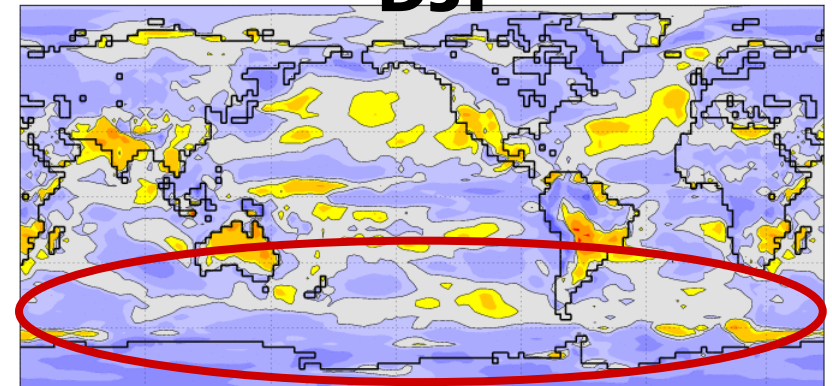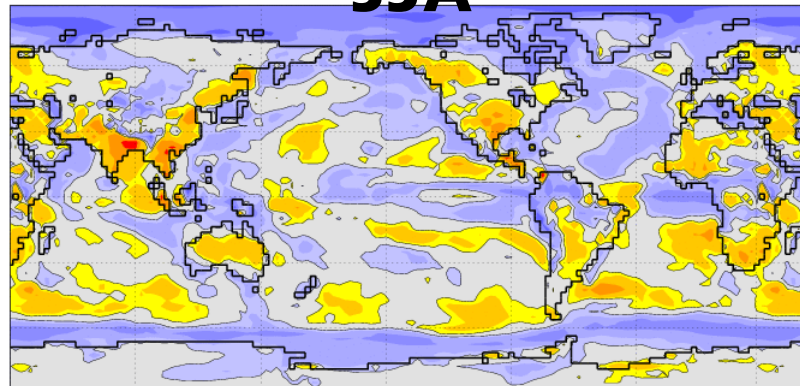
Annual predictions: examples

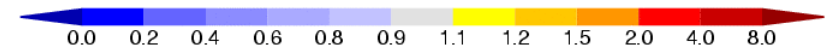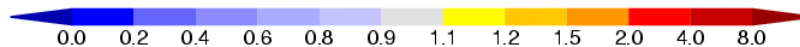System 3 annual Niño3.4 sea surface temperature forecasts (red lines) and observations (blue line).

**Nov 2008
start date**
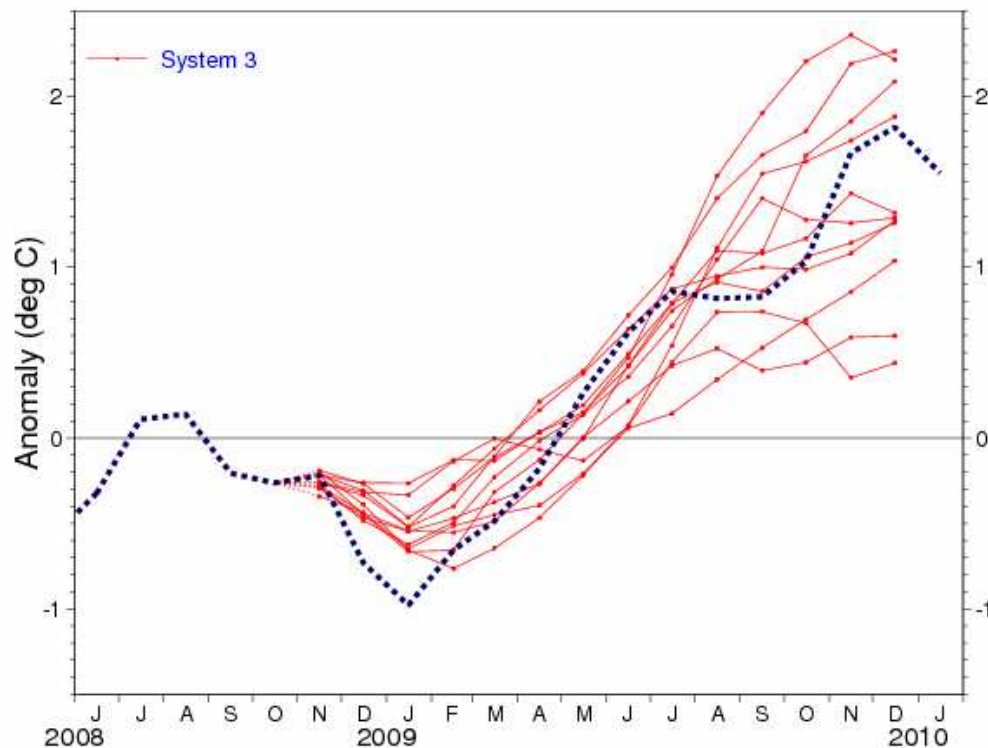
**Nov 2009
start date**
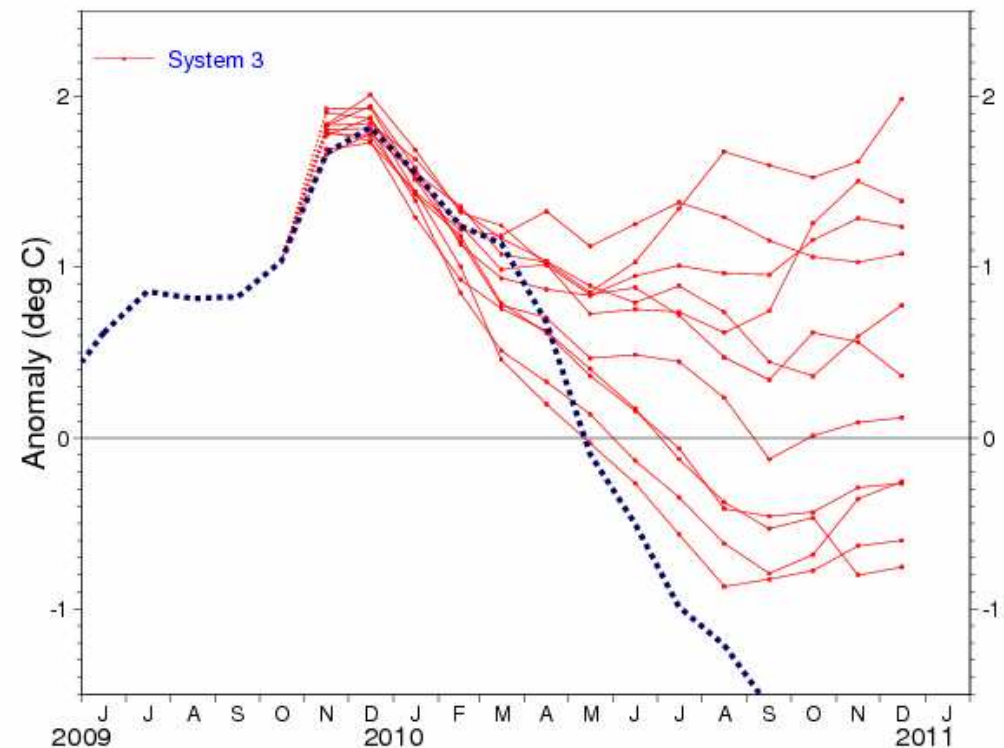
Annual predictions: ENSO

Niño3.4 time series for ERA40/Int (red dots), five-member ensemble (green box-and-whisker) and ensemble mean (blue dots) 8-10 month (DJF) re-forecasts over 1976-2005.

EC-Earth
Ratio sd: 0.83
Corr: 0.80
RPSSd: 0.55
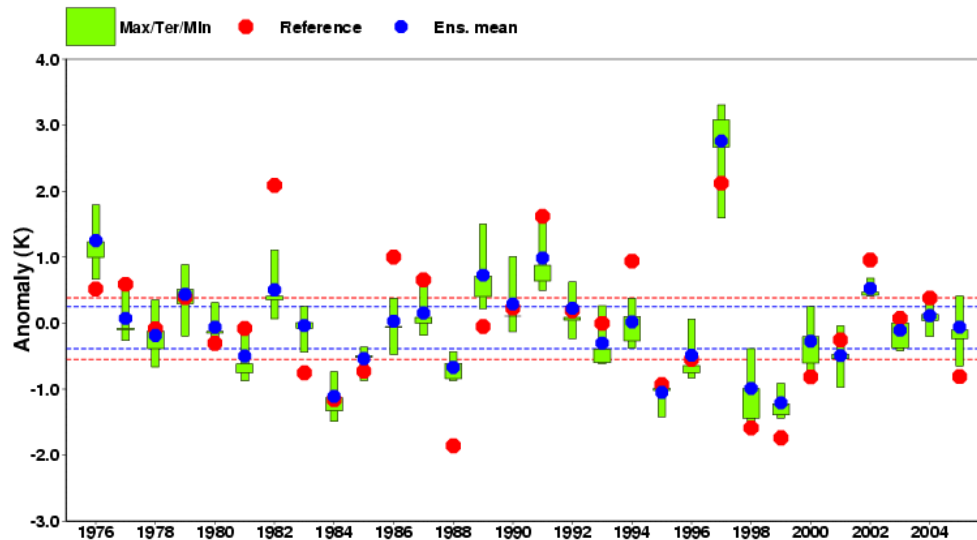
System 3
Ratio sd: 0.84
Corr: 0.87
RPSSd: 0.56
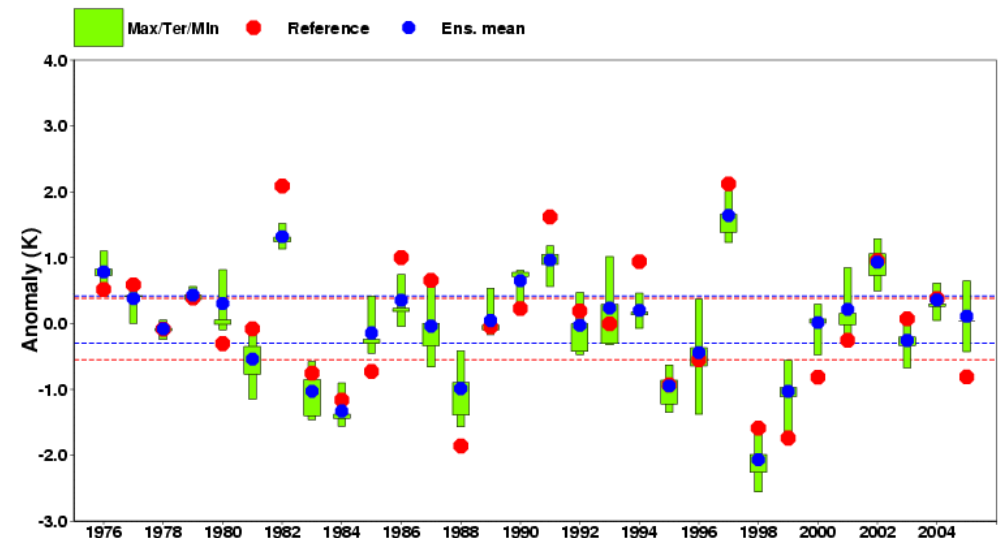
Annual predictions: ENSO

Niño3.4 ensemble-mean correlation (left) and debiased RPSS (right) for EC-Earth and System 3 five-member ensemble re-forecasts with May and November start dates over 1976-2005.

May start date, first to 13th month

November start date, first to 13th month
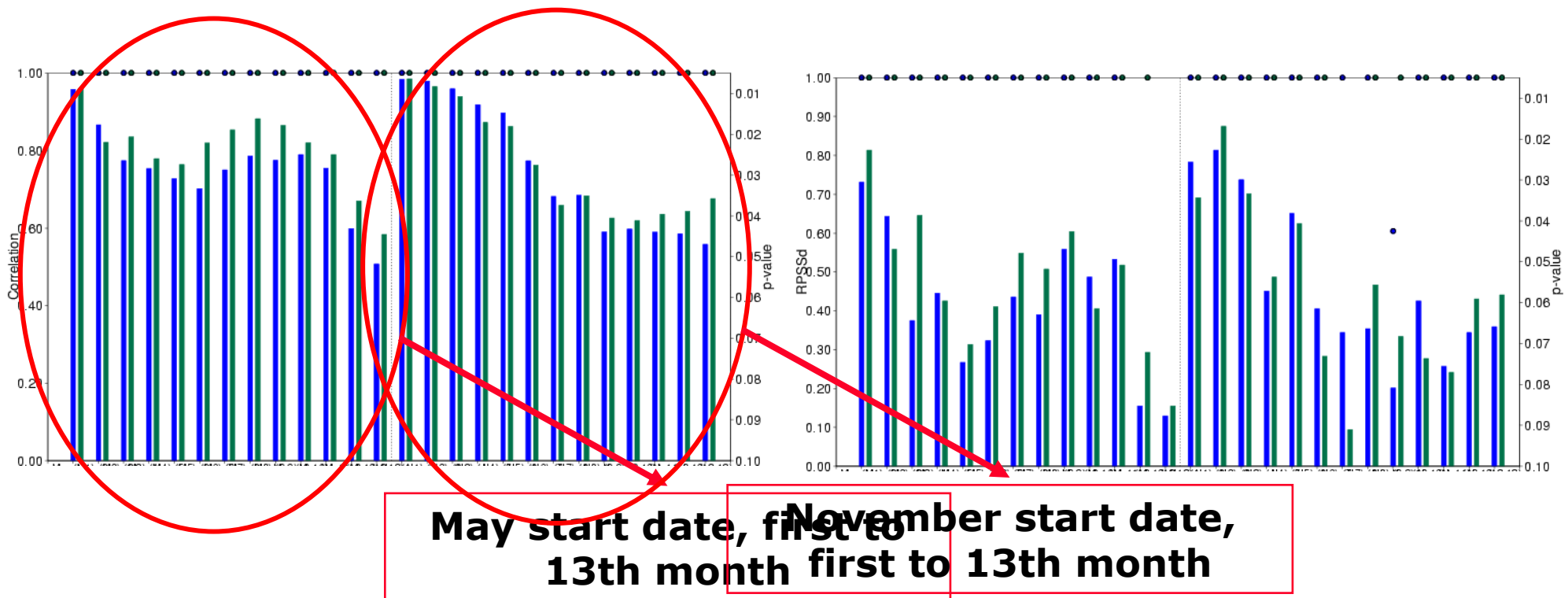
Annual predictions: ENSO

Niño3.4 probabilistic scores (and 95% conf. intervals) for EC-Earth and System 3 ensemble re-forecasts over 1976-2005.

Lower tercile threshold

ROCSS

Upper tercile threshold

RelSS
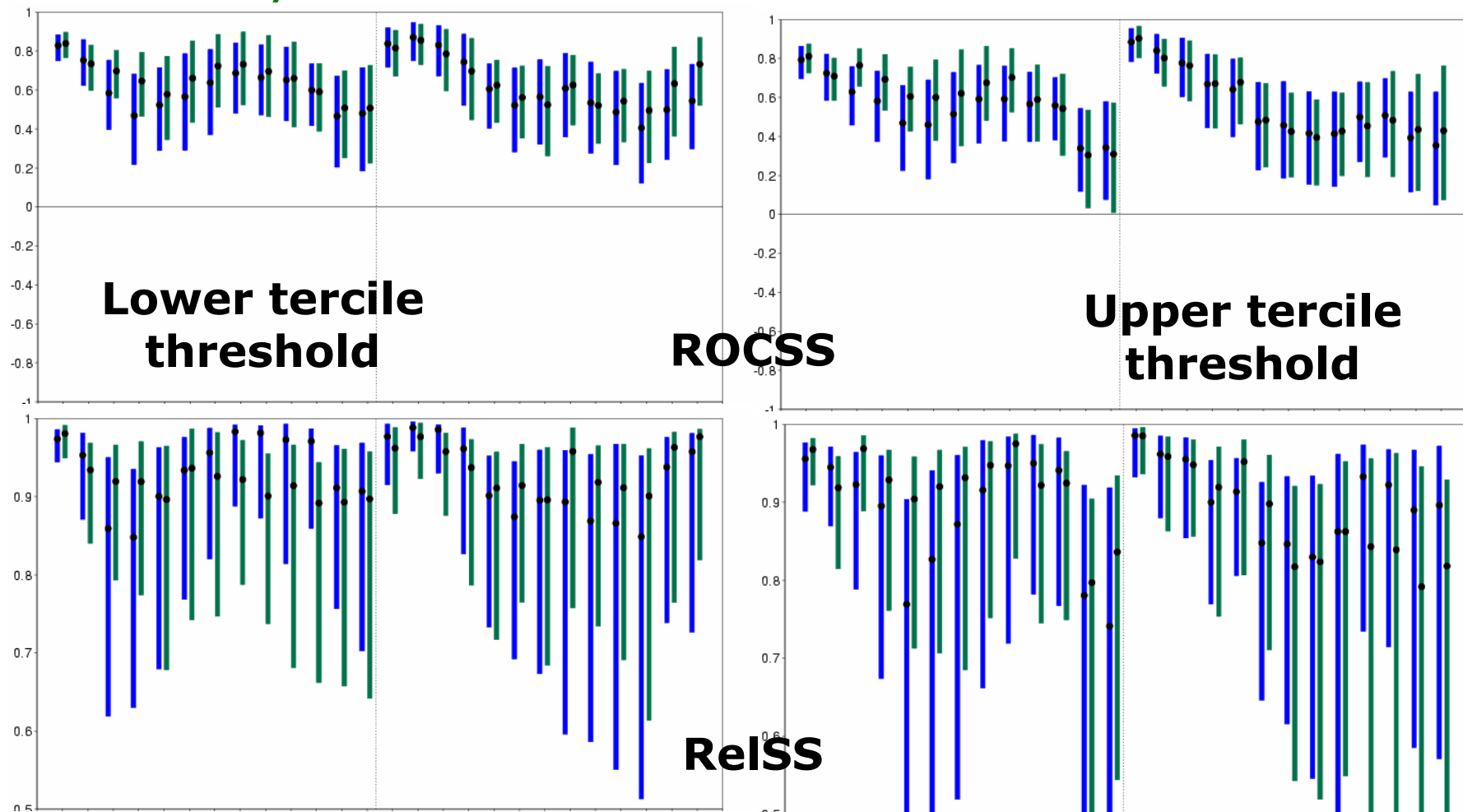
Annual predictions: other tropical oceans

Ensemble-mean correlation of different SST indices for EC-Earth and System 3 re-forecasts over 1976-2005.
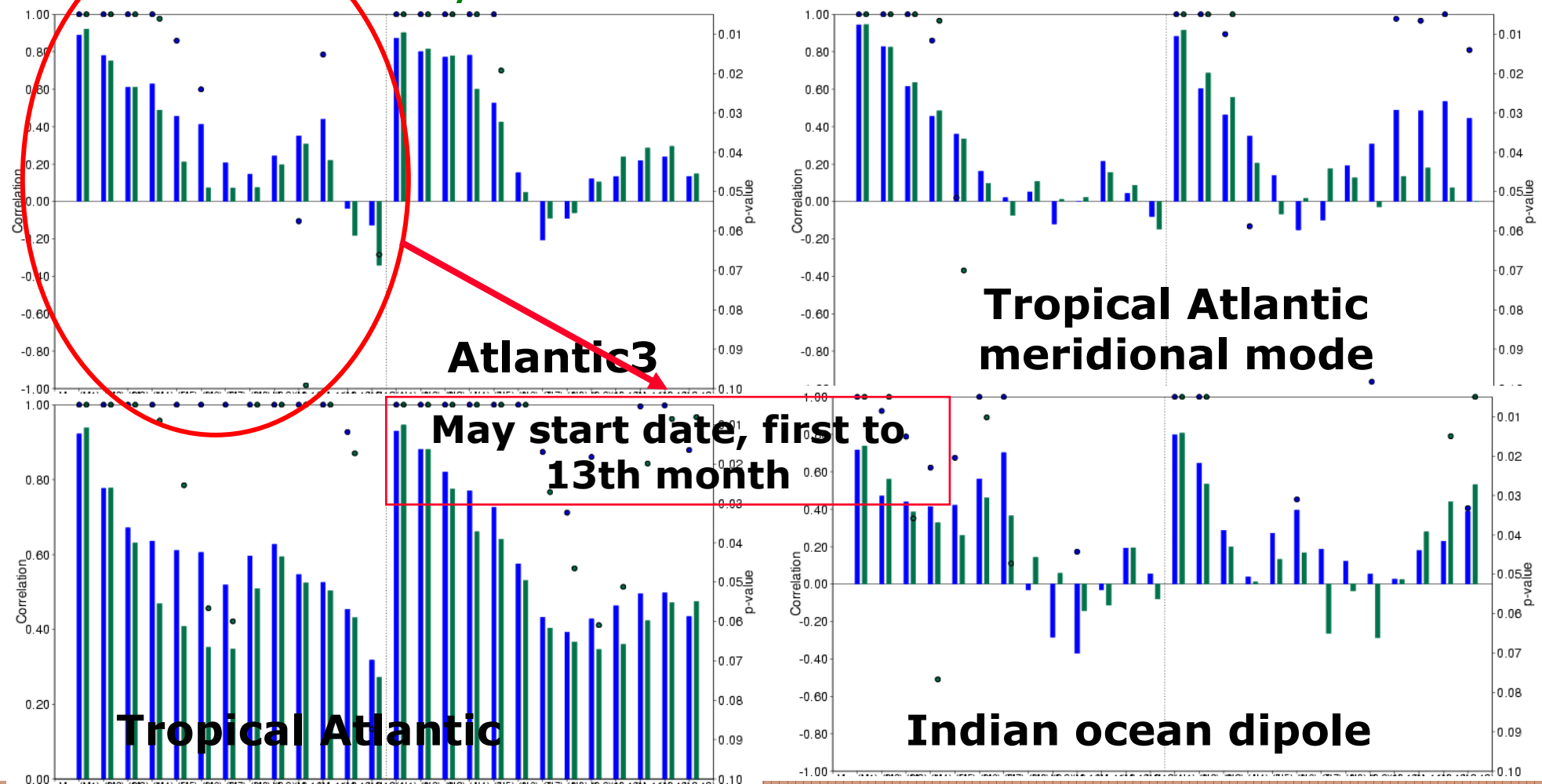
Atlantic3

Tropical Atlantic meridional mode

May start date, first to 13th month

Tropical Atlantic

Indian ocean dipole

Annual predictions: lead time effect

Ensemble-mean correlation of EC-Earth near-surface air temperature re-forecasts wrt ERA40/Int over 1976-2005. Dots for values statistically significant with 95% conf.
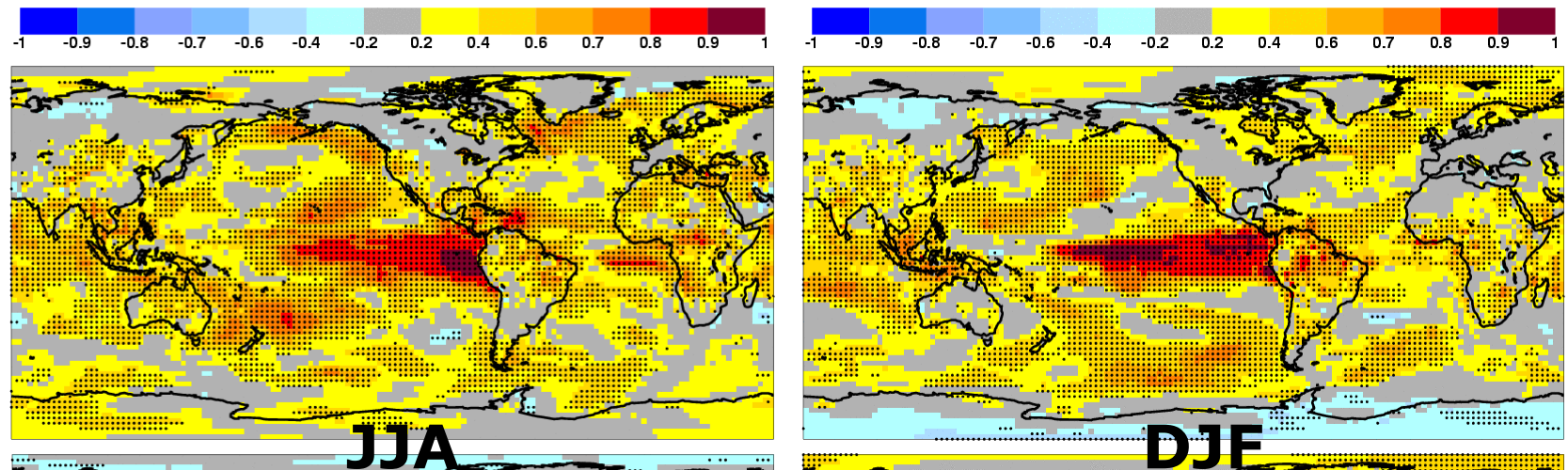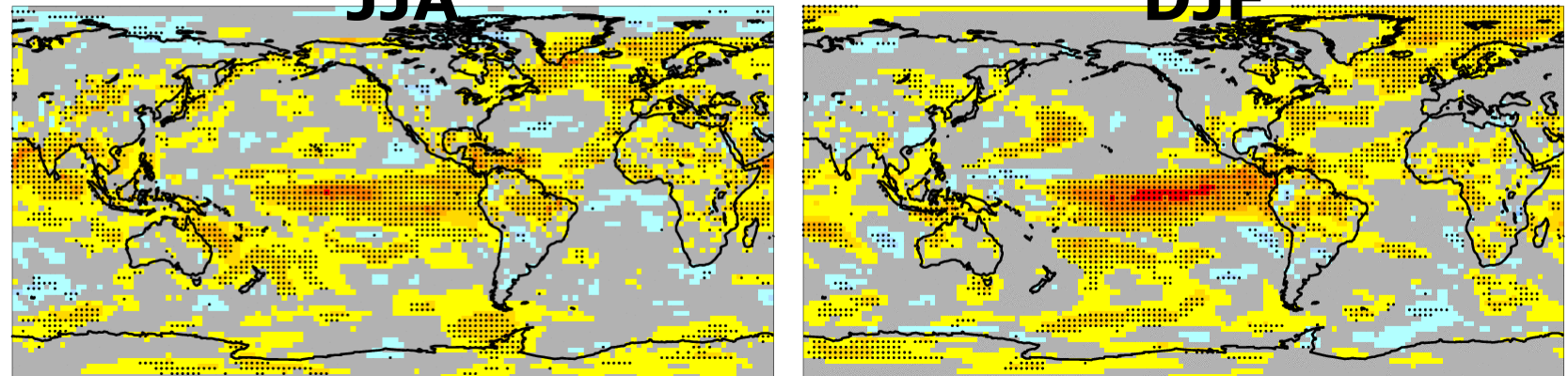
Annual predictions: predictability

Ensemble-mean correlation of EC-Earth 8-10 month near-surface air temperature re-forecasts over 1976-2005. Dots for values statistically significant with 95% conf.

Against obs.

Against model

JJA

DJF
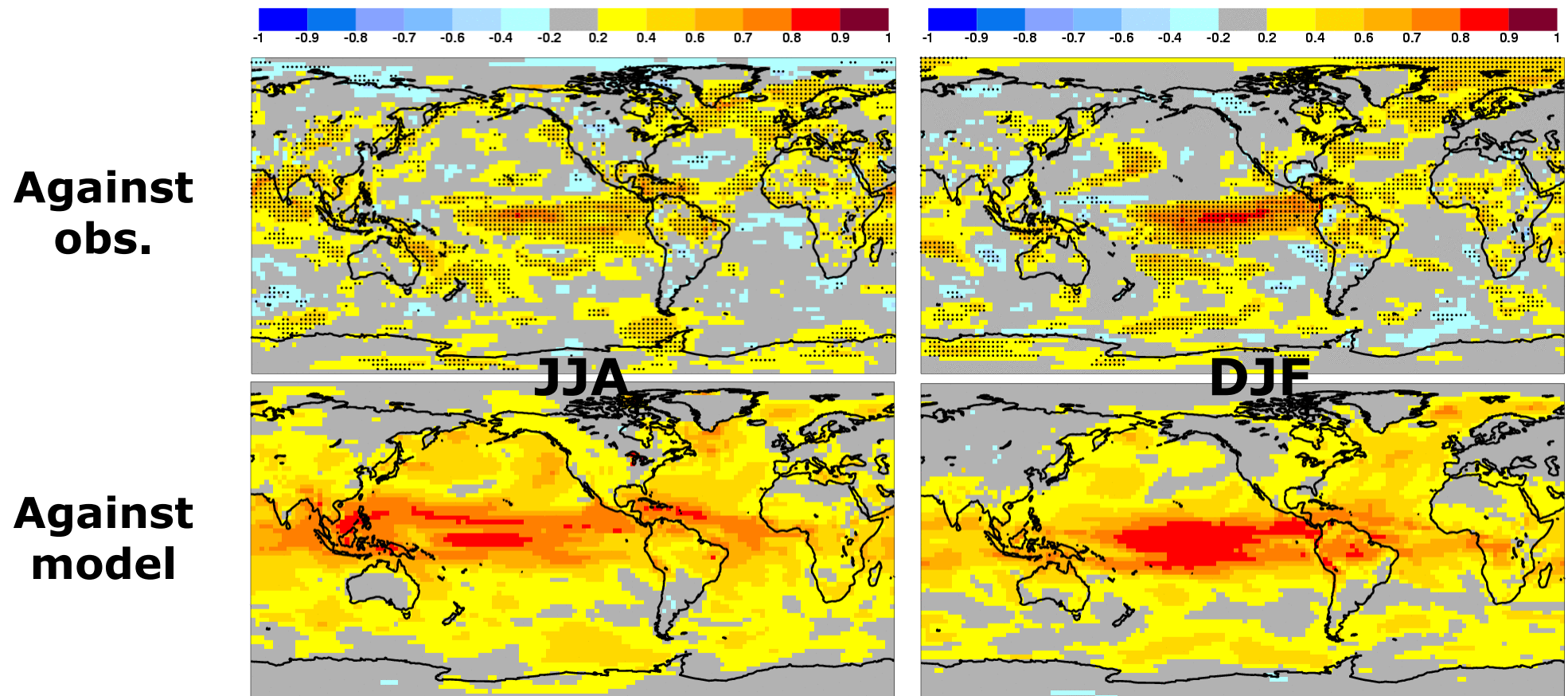
Annual predictions: lead time effect

Ensemble-mean correlation of EC-Earth precipitation re-forecasts wrt GPCP over 1980-2005. Dots for values statistically significant with 95% conf.
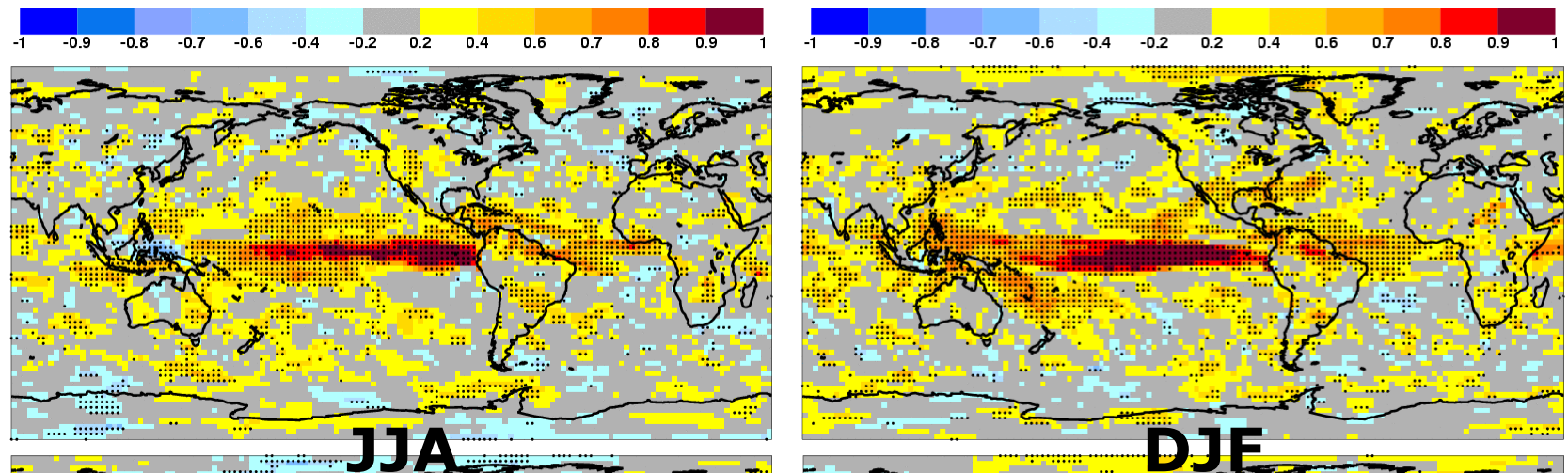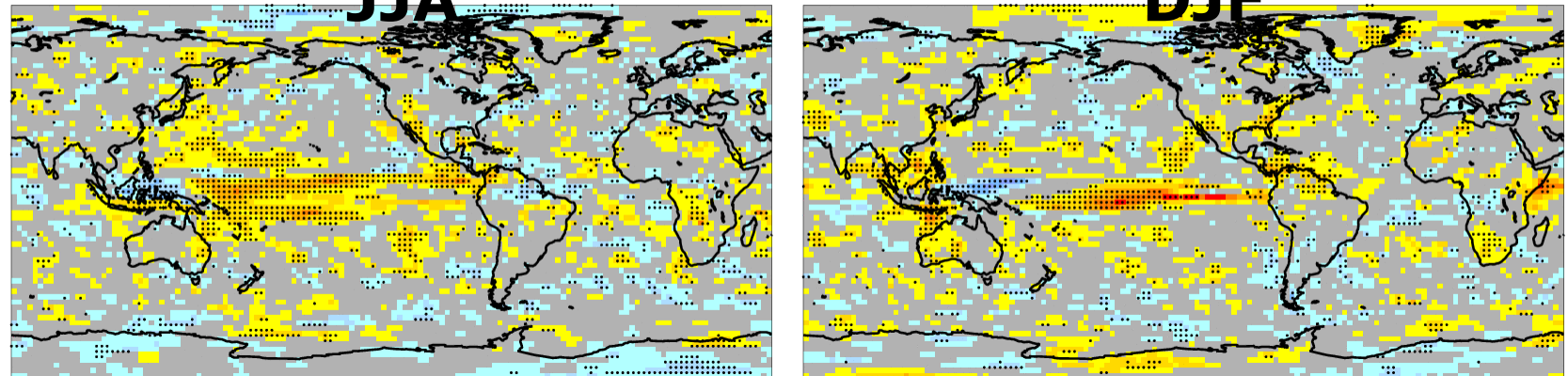
Annual predictions: predictability

Ensemble-mean correlation of EC-Earth 8-10 month precipitation re-forecasts over 1980-2005. Dots for values statistically significant with 95% conf.

Against obs.
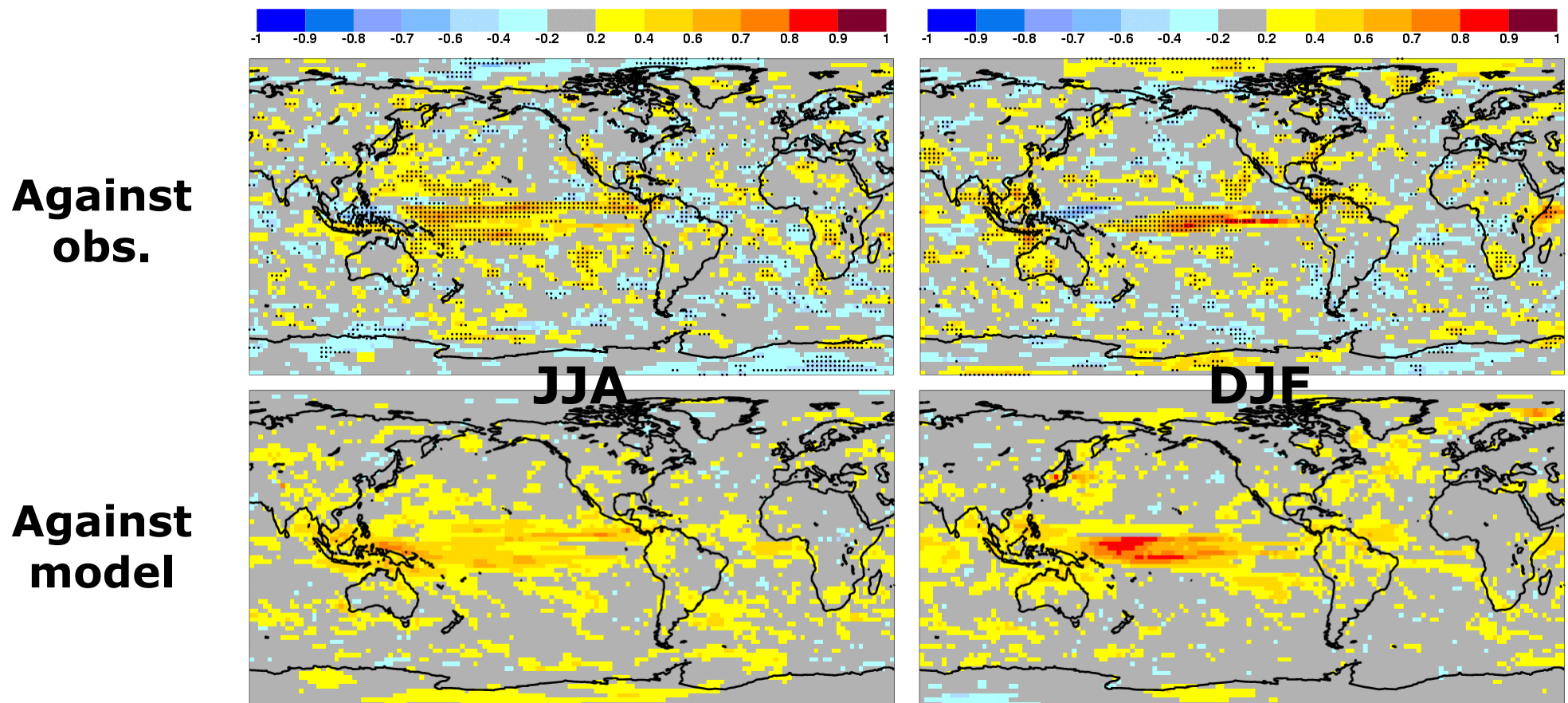
Against model

JJA

DJF

Annual predictions: annual mean

Ensemble-mean correlation of annual averages (months 2-13, Nov start) from re-forecasts (wrt ERA40/Int and GPCP) over 1976-2005. Dots for significant values with 95% conf.
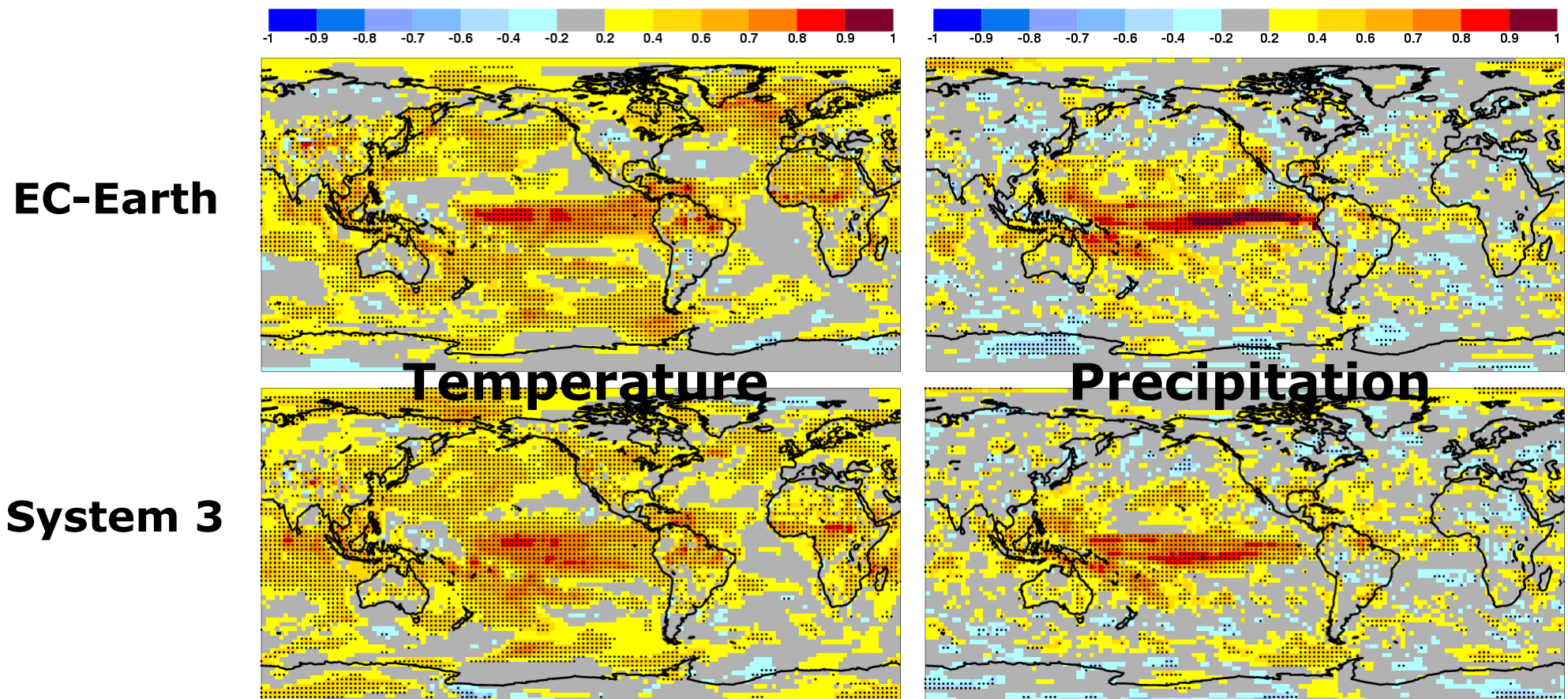
Annual predictions: regional skill

Anomaly correlation coefficient (and 95% confidence intervals) for EC-Earth, System 3 and EC-Earth/AMIP five-member ensemble near-surface temperature re-forecasts wrt ERA40/Int over 1976-2005.

Tropics
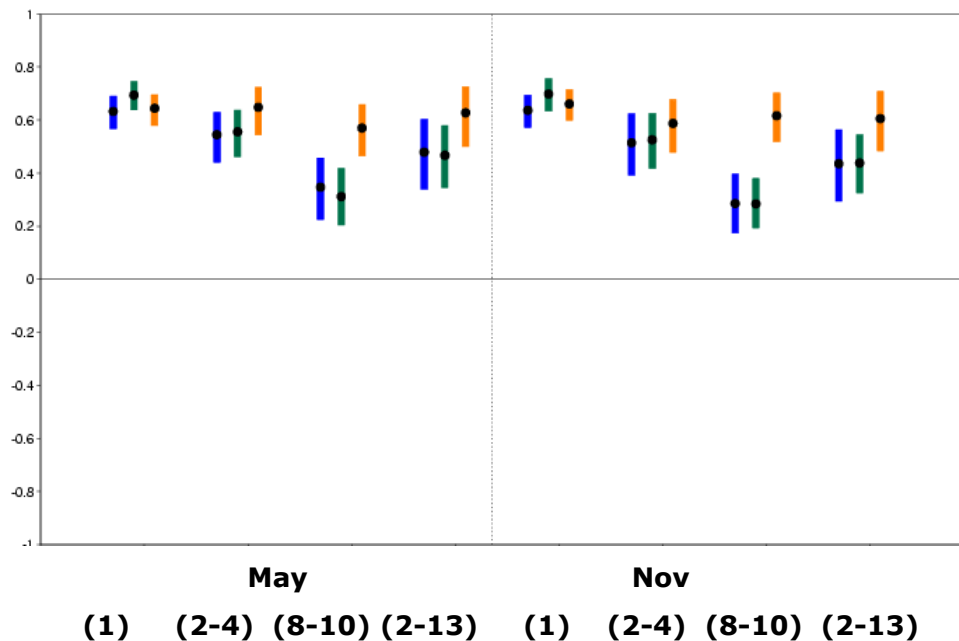
Northern Extratropics

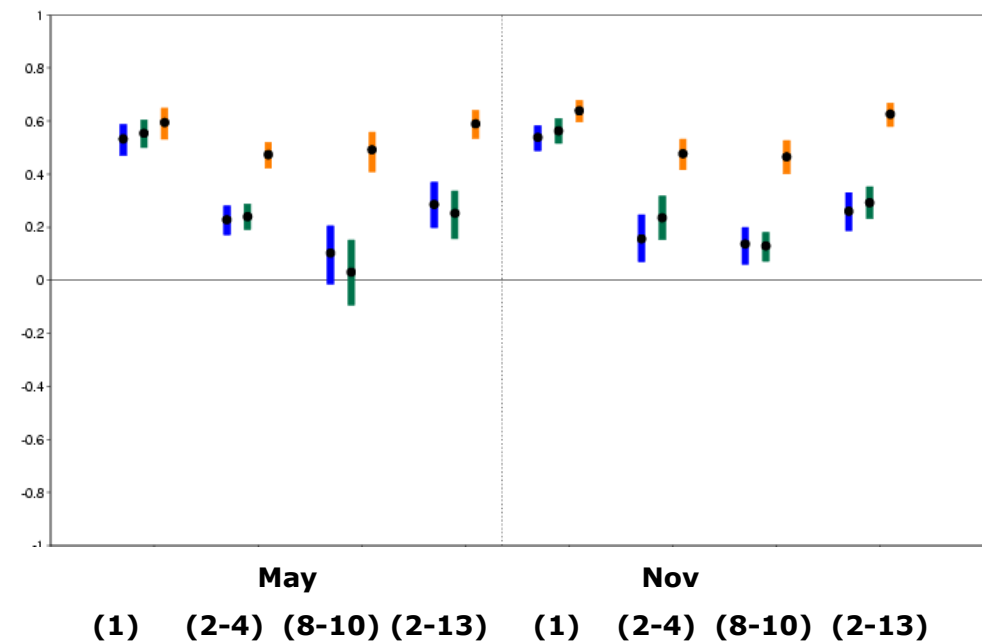# Annual predictions: regional skill

Anomaly correlation coefficient (and 95% confidence intervals) for EC-Earth, System 3 and EC-Earth/AMIP five-member ensemble precipitation re-forecasts wrt GPCP over 1980-2005.

Tropics

Northern Extratropics

Annual predictions: global mean

Ensemble-mean correlation for EC-Earth and System 3 five-member ensemble near-surface temperature re-forecasts wrt ERA40/Int over 1976-2005.
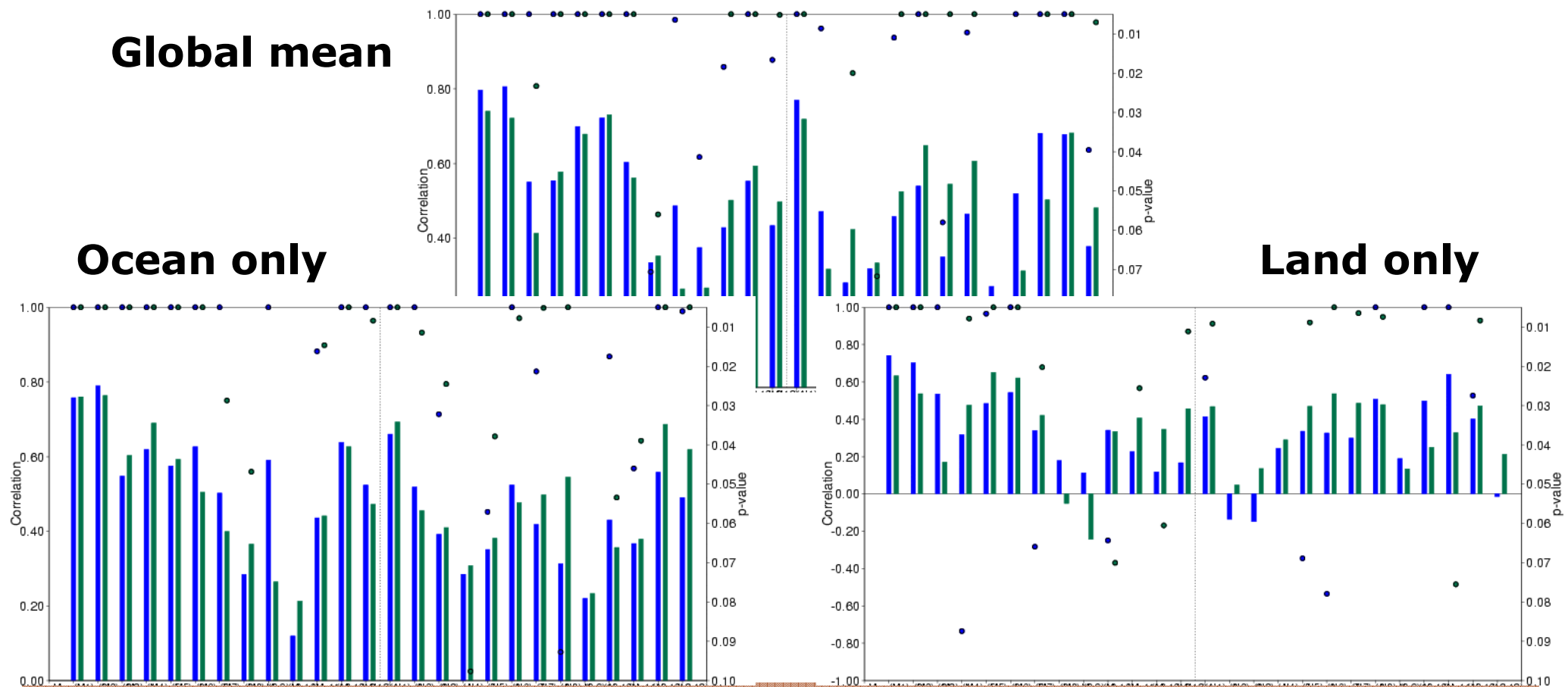
Annual predictions: Global mean

Ensemble-mean correlation for EC-Earth, System 3 and EC-Earth/AMIP five-member ensemble near-surface temperature re-forecasts wrt ERA40/Int over 1976-2005.
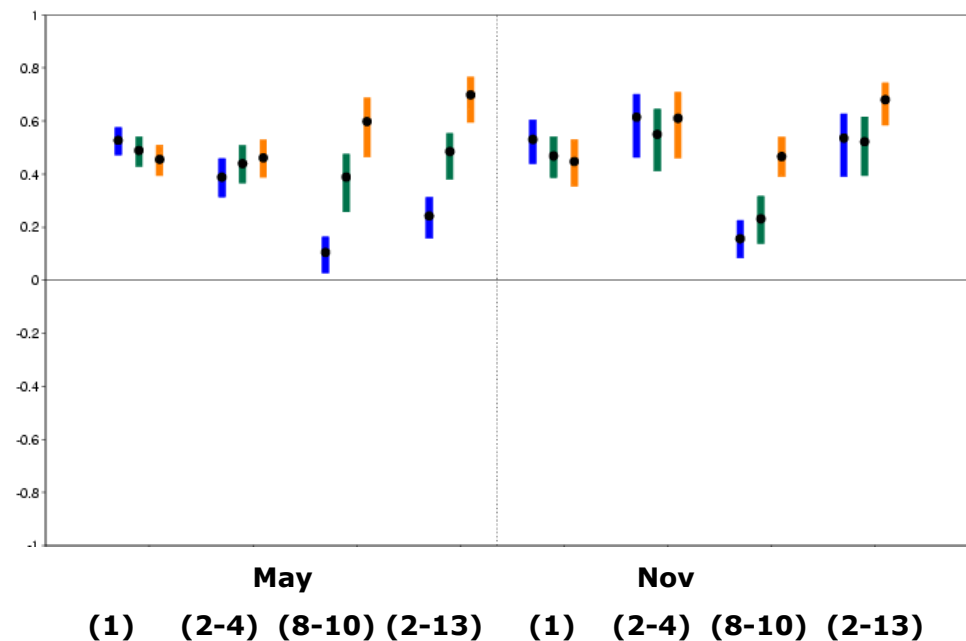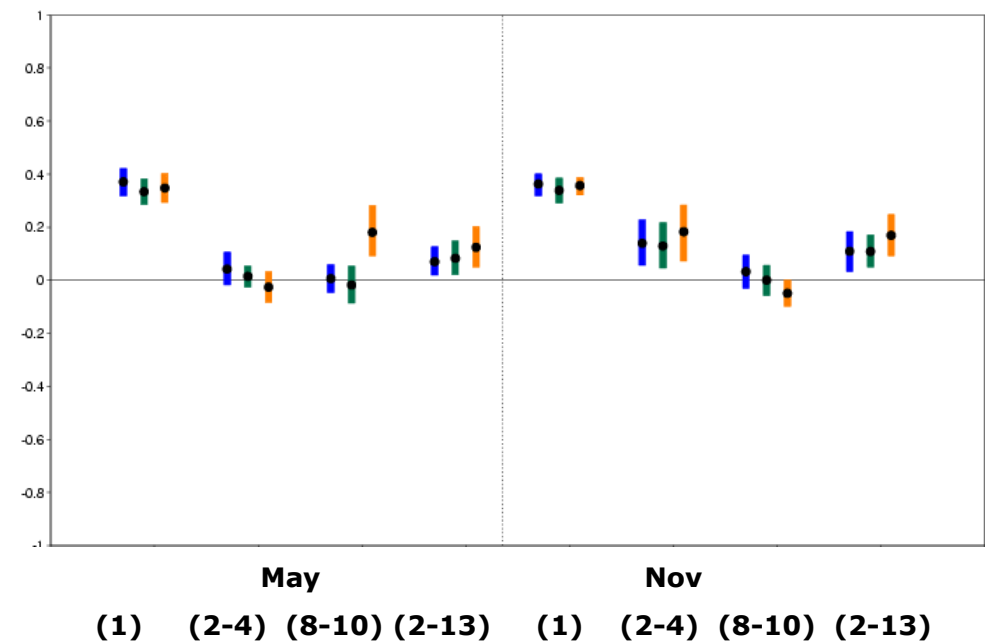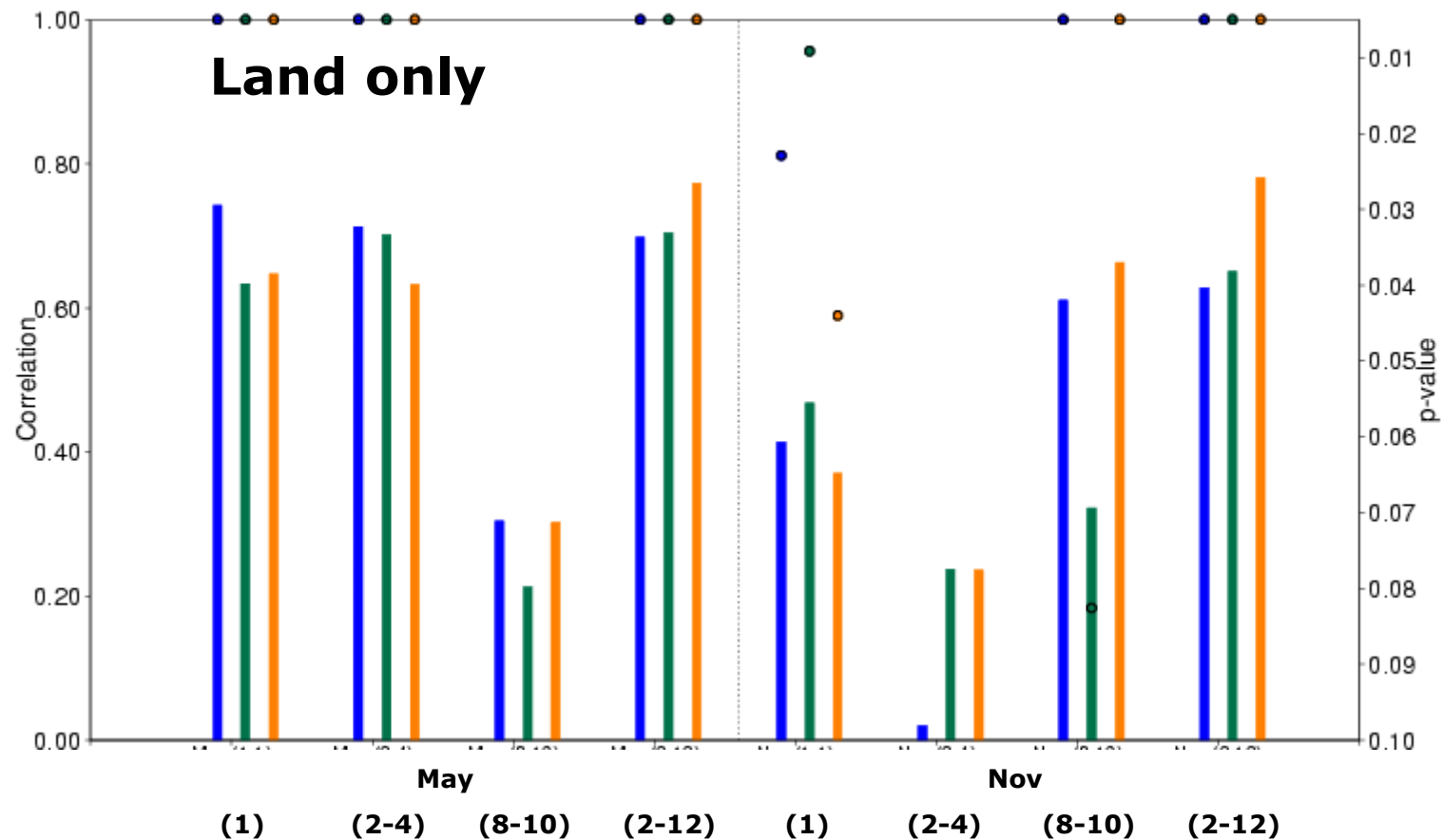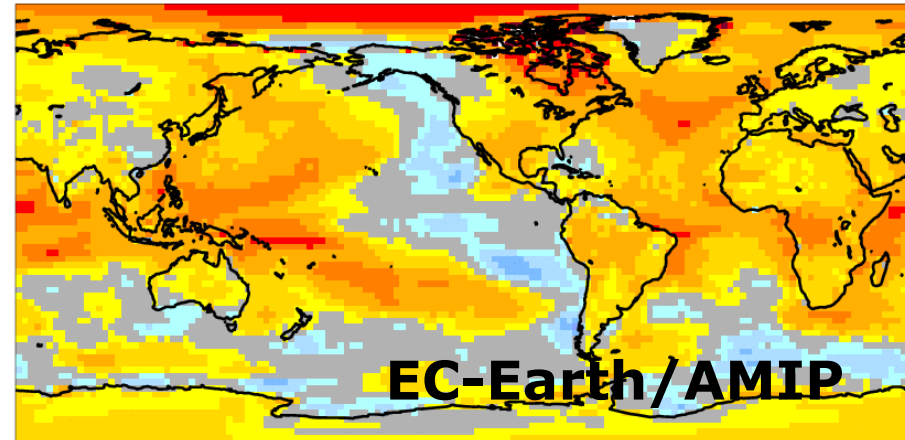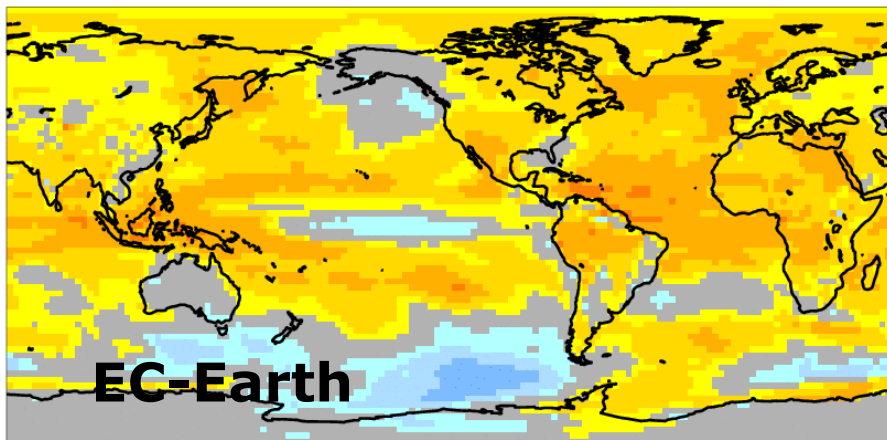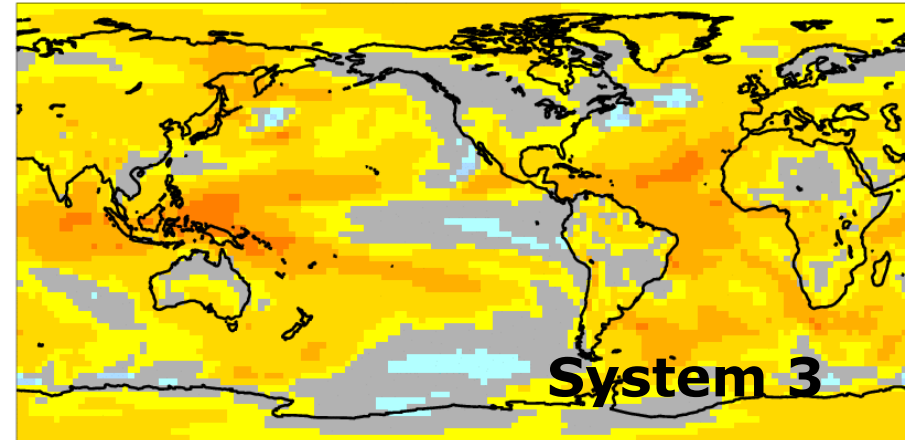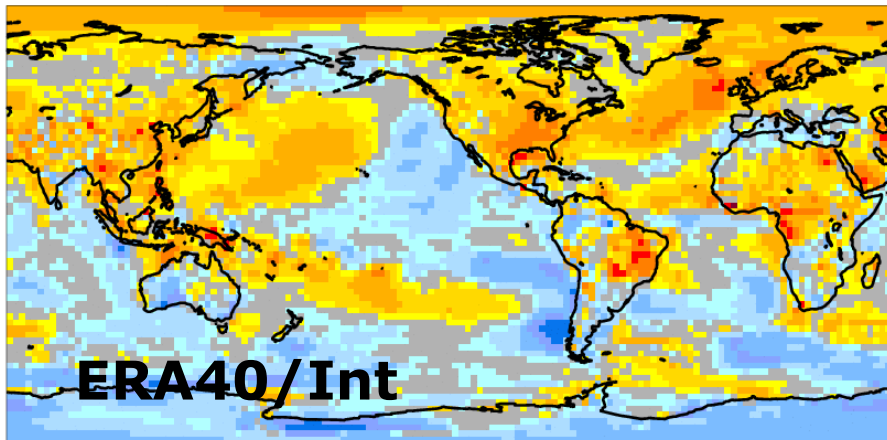
Annual predictions: trends

Normalized trends of near-surface temperature 8-10 month (DJF) re-forecasts over 1976-2005.

Multi-annual forecast experimental setup

- One forecast system: EC-Earth v2.2 (IFS/NEMO)

- Initial conditions: ERA40/ERAInt atmosphere and land, ORA-S3 and NEMOVAR-COMBINE ocean, DFS4.3 sea ice

- 1) Five-member ensemble hindcasts up to 24 months with two start dates per year (May and November) over 1976-2005 and 2) five-member ensemble hindcasts up to 120 months with one start date every five years over 1960-2005

- Ensemble from five-member ocean analysis and atmospheric perturbations (singular vectors) added to each member

- Initial conditions valid for 0 GMT on the 1st of a month

Interannual predictions: regional skill

Anomaly correlation coefficient (and 95% confidence intervals) for EC-Earth re-forecasts (ensemble members and ensemble mean) over 1975-2005.

Tropics precipitation
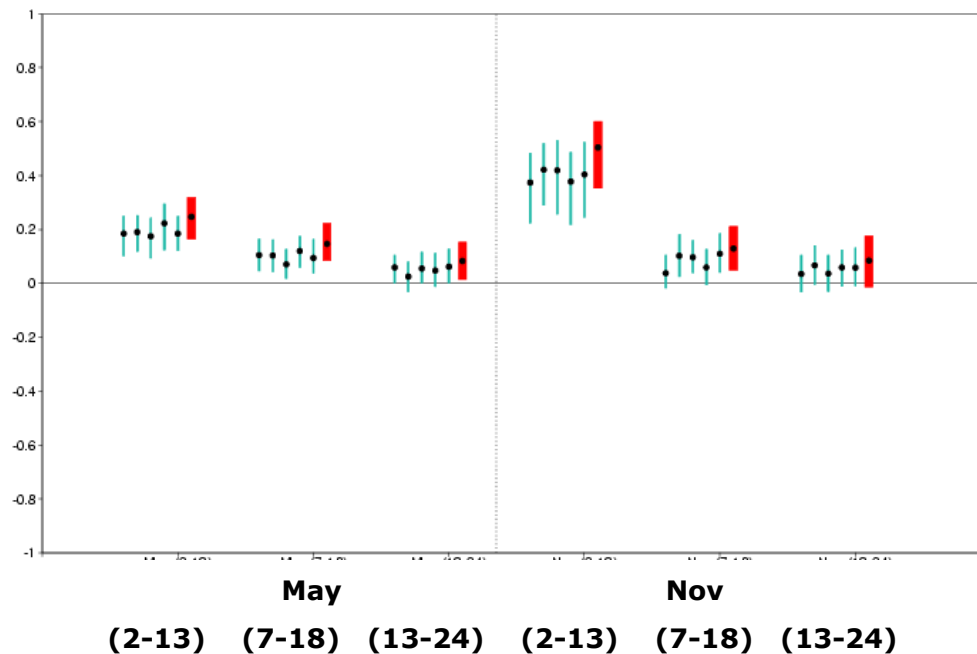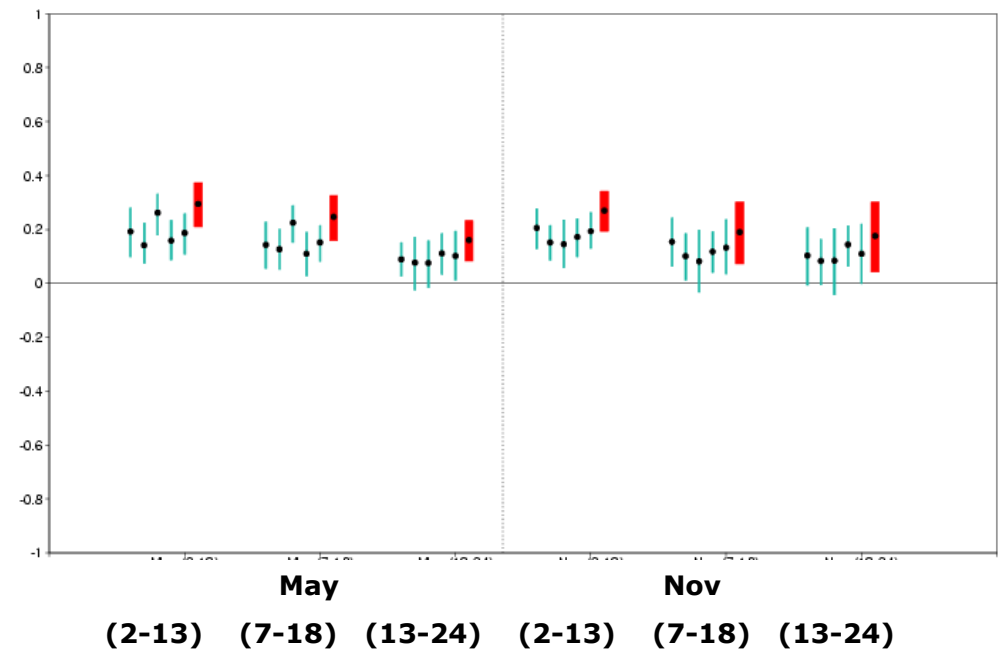
Northern Extratropics temperature

May

(2-13)   (7-18)   (13-24)

Nov

(2-13)   (7-18)   (13-24)

May

(2-13)   (7-18)   (13-24)

Nov

(2-13)   (7-18)   (13-24)
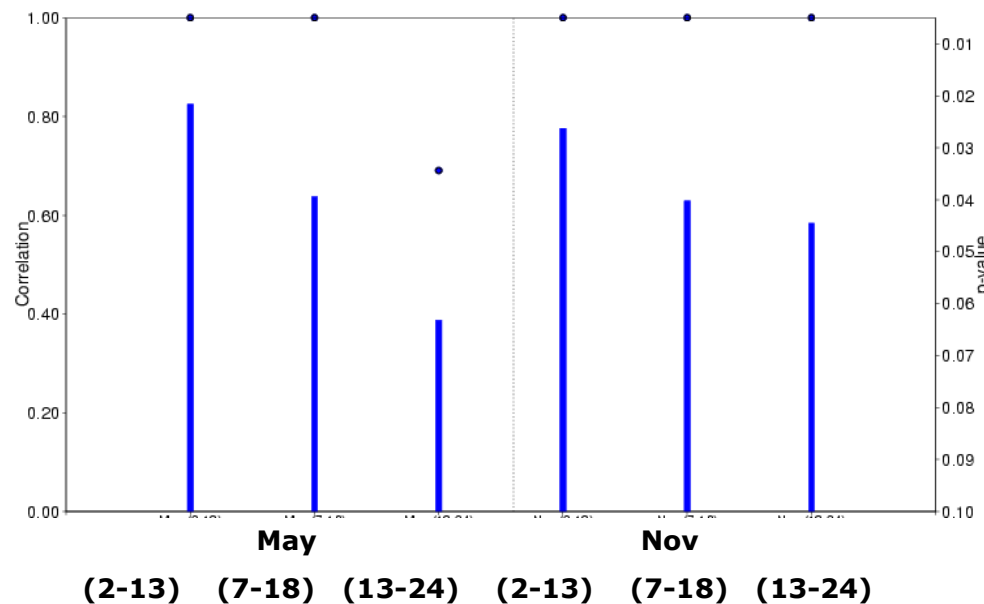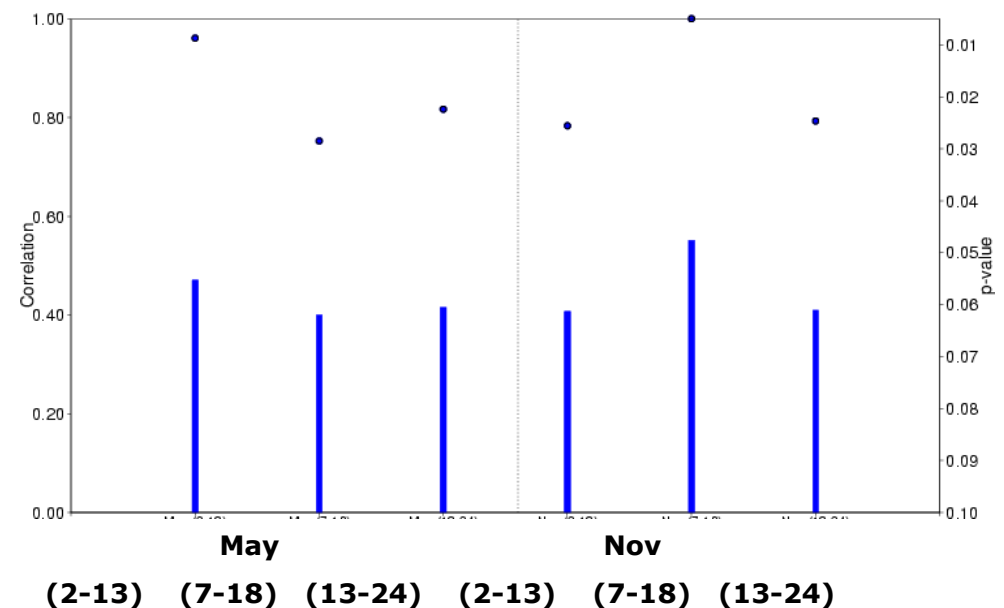
Interannual predictions: regional mean

Ensemble-mean correlation for EC-Earth five-member ensemble re-forecasts with May and November start dates over 1976-2005.
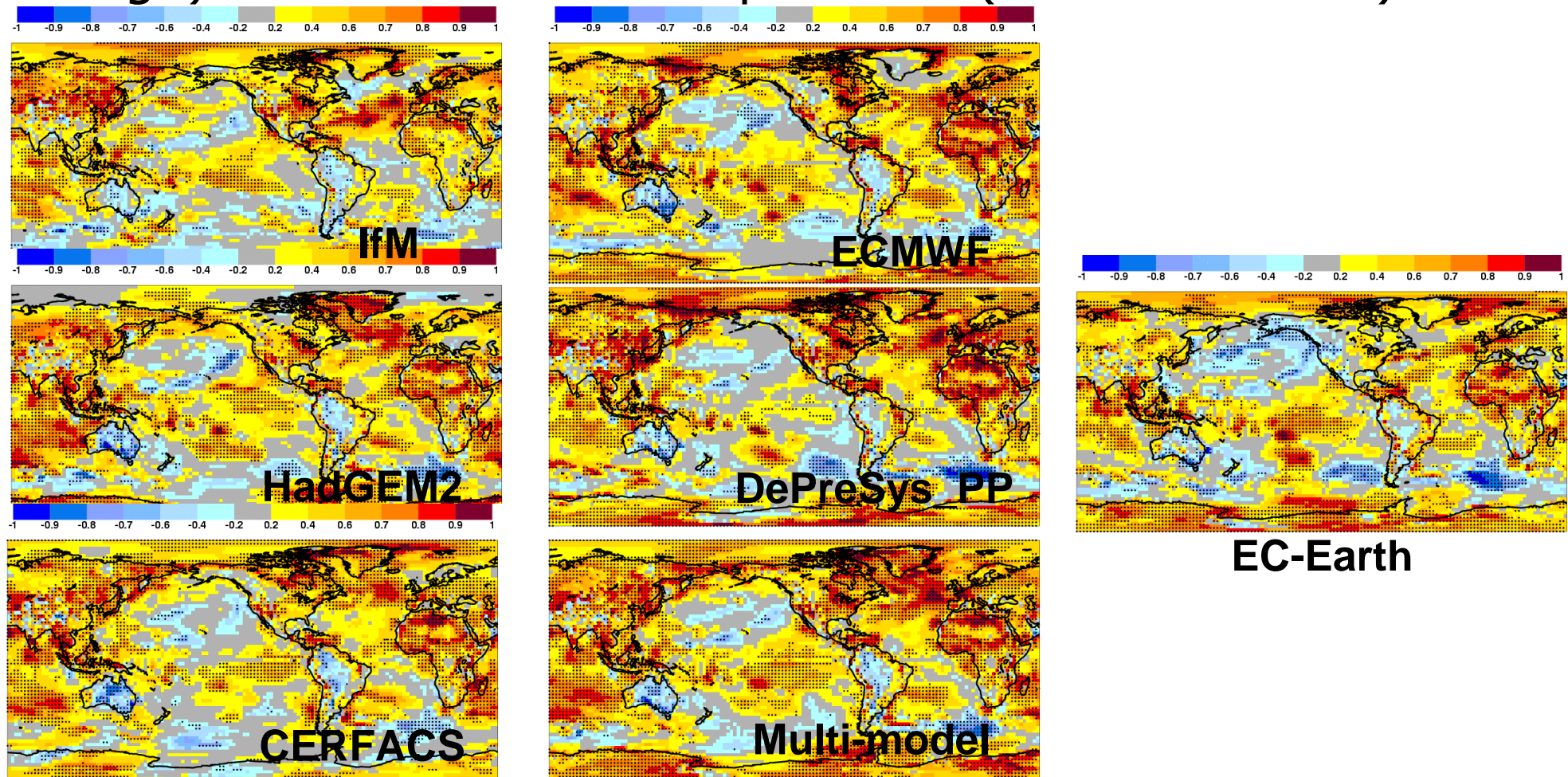
Niño3.4

Southern Europe temperature

Interannual predictions: ensemble mean

Ensemble-mean correlation for decadal forecasts (1-4 year average) of near-surface temperature (ten start dates)

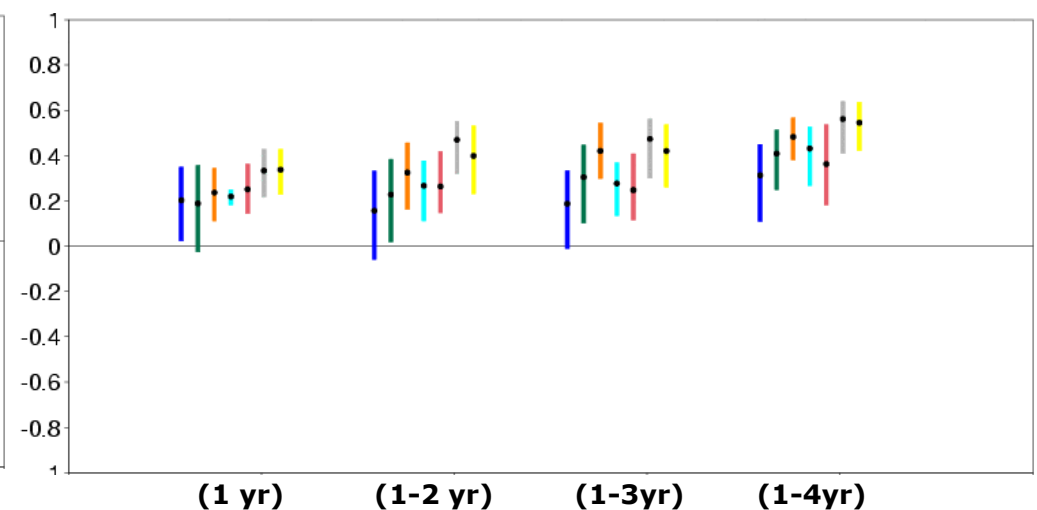# Interannual predictions: regional skill

Anomaly correlation coefficient (and 95% confidence intervals) for EC-Earth (5), IFS/HOPE-35R3 (3), CERFACS (3), IfM (3), HadGEM2 (3), DePreSys_PP (9) and ENSEMBLES multi-model (12) near-surface air temperature re-forecasts wrt ERA40/Int over 1960-2005.
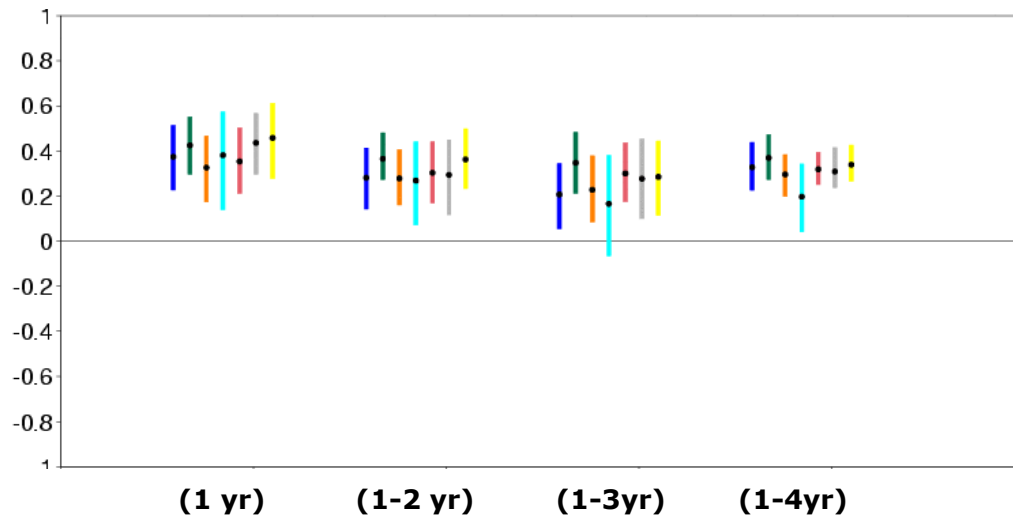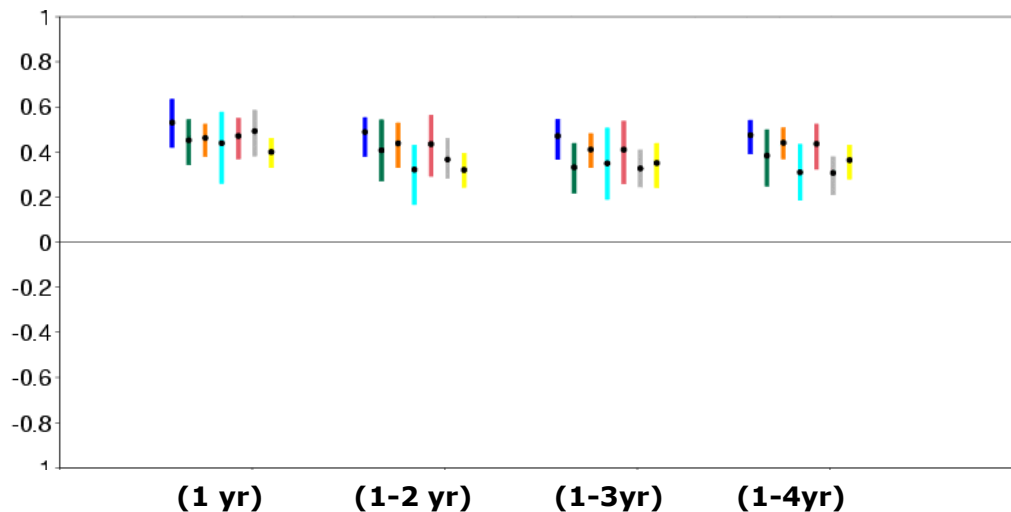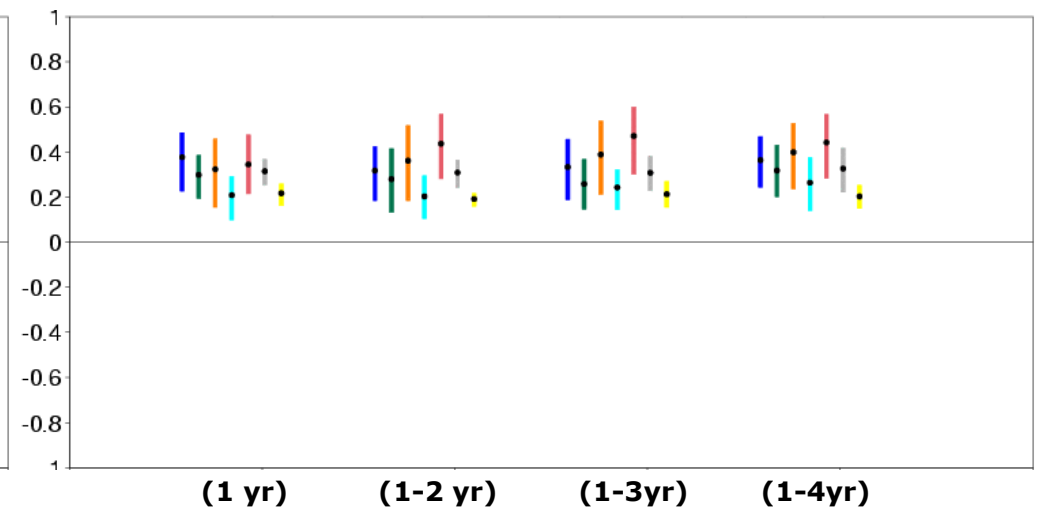

Tropics

Northern Extratropics

Interannual predictions: regional skill

Perfect-model anomaly correlation coefficient (and 95% confidence intervals) for EC-Earth (5), IFS/HOPE-35R3 (3), CERFACS (3), IfM (3), HadGEM2 (3), DePreSys_PP (9) and ENSEMBLES multi-model (12) near-surface air temperature re-forecasts wrt ERA40/Int over 1960-2005.
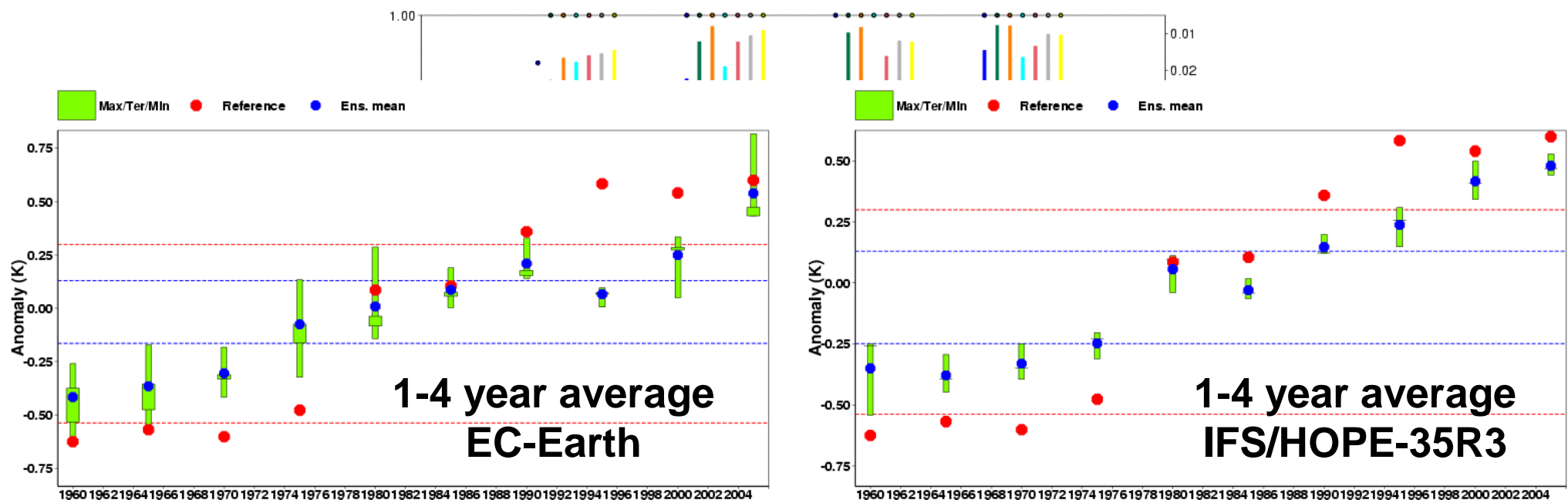

Tropics

Northern Extratropics

Interannual predictions: regional mean

Ensemble-mean correlation (and p value, right-hand side scale) for EC-Earth (5), IFS/HOPE-35R3 (3), CERFACS (3), IfM (3), HadGEM2 (3), DePreSys_PP (9) and ENSEMBLES multi-model (12) near-surface air temperature re-forecasts wrt ERA40/Int over 1960-2005.

Land-temperature

Interannual predictions: regional mean

Ensemble-mean correlation (and p value, right-hand side scale) for EC-Earth (5), IFS/HOPE-35R3 (3), CERFACS (3), IfM (3), HadGEM2 (3), DePreSys_PP (9) and ENSEMBLES multi-model (12) near-surface air temperature re-forecasts wrt ERA40/Int over 1960-2005.
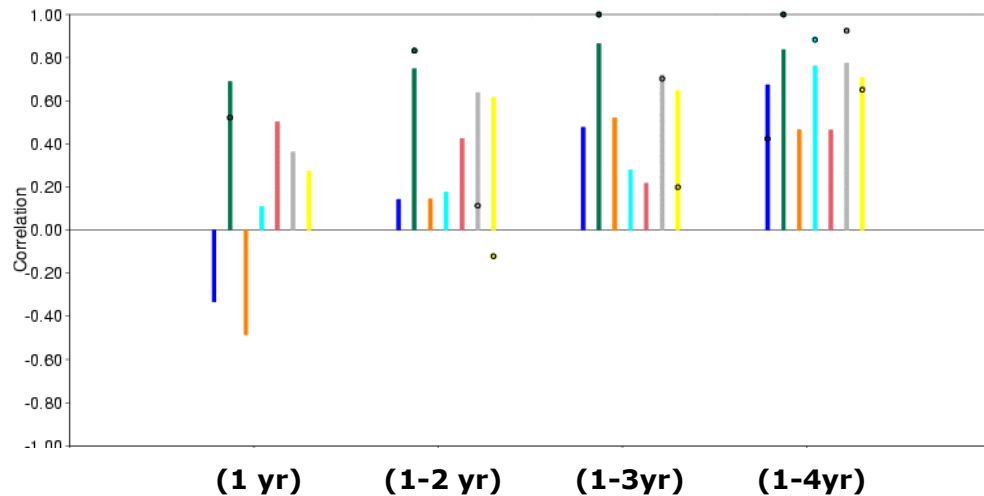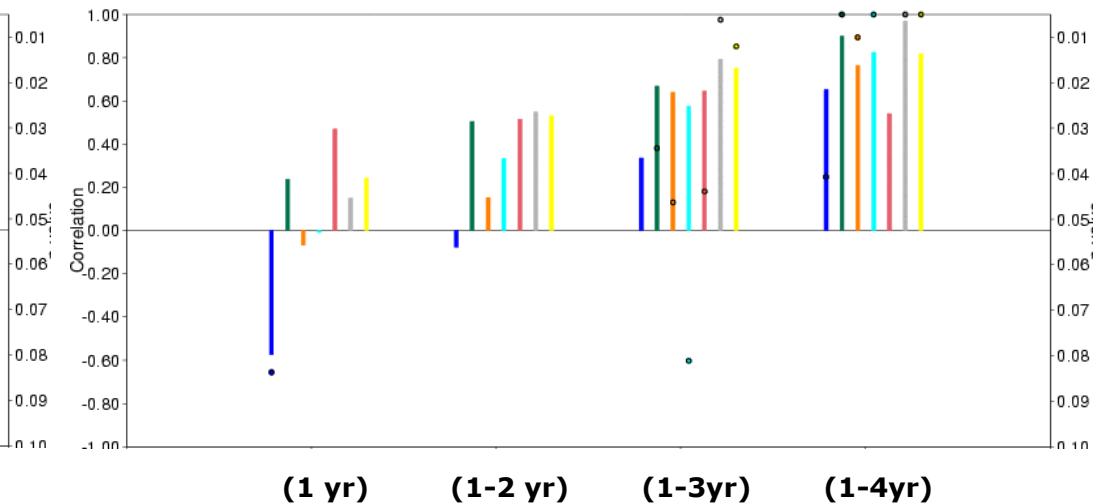

Northern Europe

Southern Europe

Some thoughts

- Substantial systematic error, including lack of reliability, is still a fundamental problem in dynamical forecasting and forces *a posteriori* corrections. Forecast calibration such as forecast assimilation is still needed.

- There is statistically significant skill in ENSO and other tropical SSTs beyond the first few months of the forecasts.

- The skill at the interannual time scale is linked to the correct prediction of ENSO and global warming.

- Some problems are found in EC-Earth with land warming.

- The impact of many more processes remains to be analyzed: sea ice, anthropogenic aerosols, …

- The seamless has still to be developed further.